CHAPTER 5. ENGINEERING ANALYSIS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 5. ENGINEERING ANALYSIS

5.1 INTRODUCTION

After conducting the screening analysis, the Department of Energy (DOE) performed an engineering analysis based on the remaining design options. The engineering analysis consists of estimating the energy consumption and costs of products at various levels of increased efficiency. This section provides an overview of the engineering analysis (section 5.1), considers technologies which are unable to be analyzed for this rulemaking (section 5.2), discusses established product classes (section 5.3), defines baseline unit specifications (section 5.4.1), discusses incremental efficiency levels (section 0), explains the methodology used during data gathering (5.4.2.3) and discusses the analysis and results (section 5.6). DOE completed separate engineering analysis for residential clothes dryers and room air conditioners.

The primary inputs to the engineering analysis are baseline product information from the market and technology assessment (chapter 3 of the technical support document (TSD)) and technology options that are not eliminated in the screening analysis (chapter 4). Additional inputs include cost and energy efficiency data, which DOE received from the Association of Home Appliance Manufacturers (AHAM) and qualified and supplemented through tear-down analysis, energy modeling, and manufacturer interviews. The primary output of the engineering analysis is a set of cost-efficiency curves. In the subsequent markups analysis (chapter 7), DOE determined customer (*i.e.*, product purchaser) prices by applying distribution markups, sales tax and contractor markups. After applying these markups, they serve as the input to the building energy-use and end-use load characterization (chapter 6) and the life-cycle cost (LCC) and payback period (PBP) analysis (chapter 8).

DOE typically structures its engineering analysis around one of three methodologies. These are: (1) the design-option approach, which calculates the incremental costs of adding specific design options to a baseline model; (2) the efficiency-level approach, which calculates the relative costs of achieving increases in energy efficiency levels, without regard to the particular design options used to achieve such increases; and/or (3) the reverse engineering or cost-assessment approach, which involves a "bottom-up" manufacturing cost assessment based on a detailed bill of materials derived from teardowns of the product being analyzed. Deciding which methodology to use for the engineering analysis depends on the product, the design options under study, and any historical data that DOE can draw on.

5.2 TECHNOLOGIES UNABLE TO BE INCLUDED IN THE ANALYSIS

In performing the engineering analysis, DOE did not consider for analysis certain technologies that met the screening criteria but were unable to be evaluated for one or more of the following reasons: (1) data are not available to evaluate the energy efficiency characteristics of the technology; (2) available data suggest that the efficiency benefits of the technology are negligible; and (3) certain technologies cannot be measured according to the conditions and methods specified in the existing test procedure. In the first case, DOE is unable to adequately assess how these technologies impact annual energy consumption. In other cases, available data suggested that some of the design options resulted in such small energy savings as to be negligible. Because DOE intends to focus on the technologies with measurable impact on efficiency, design options with negligible energy savings have been eliminated from further consideration.

5.2.1 Clothes Dryers

5.2.1.1 Reverse tumble

Manufacturers interviewed as part of the preliminary manufacturer interview analysis indicated that such a feature is used primarily for fabric care. The benefits of reverse tumbling include prevention of balling and wrinkling of the clothes load. No manufacturer indicated they use, or would consider, reverse tumble for increasing efficiency. Tests conducted by one manufacturer, in fact, found that the small size of the test cloths in the DOE test procedure prevents balling and thus no energy efficiency benefit can be measured.[1] At least one manufacturer stated that reverse tumble could actually reduce efficiency by stopping the drum rotation while it is changing directions. For reasons of no demonstrable energy savings and uncertainty as to whether its impacts can be measured by the existing test procedure, DOE will not further analyze reverse tumble.

5.2.1.2 Improved termination

Improved cycle termination is potentially possible by means of more accurate moisture sensors or by incorporating temperature and moisture sensors together. Alternatively, algorithms may be developed to more accurately detect end-of-cycle conditions. While each of these approaches may produce real-world energy savings by preventing consumers from over-drying the clothes load, the DOE test procedure requires that the test be terminated as soon as a certain level of dryness is achieved. A fixed field use factor is then applied to the measured energy consumption depending on whether timed or automatic cycle termination is present. Therefore, improved cycle termination cannot be measured by the test procedure. As discussed in chapter 3 of this TSD, DOE proposed amendments to the clothes dryer test procedure to more accurately account for automatic cycle termination. However, DOE determined that the proposed amendments for automatic cycle termination do not adequately measure the energy consumption of clothes dryers equipped with such systems using the test load specified in the DOE test procedure. As a result, in the test procedure final rule published in the *Federal Register* on January 6, 2011 (76 FR 972) (hereafter the January 2011 TP Final Rule), DOE did not adopt the proposed amendments for automatic cycle termination (see chapter 3 of this TSD for more details). As a result, for this analysis, DOE did not further analyze improved termination.

5.2.2 Room Air Conditioners

5.2.2.1 Improved Fin Design

The louvered, raised-lance, or slit-fin fin designs currently used in nearly all room air conditioners are the most effective technologies for heat transfer to air. These designs work by repeatedly interrupting the surface in the flow direction, which prevents thermal boundary layers from growing. The air near the fin remixes with the bulk flow at the end of each louver, and a new boundary layer forms on the next louver. A similar approach is used in high performance heat exchangers in nearly all applications for which high heat transfer is required without incurring high penalties for air-side pressure drop. DOE is not aware of any other improved fin technology that can make further improvements in heat exchanger performance for room air conditioners. Hence, DOE did not further analyze this technology.

5.2.2.2 Improved Tube Design

Rifled tubes are currently used in nearly all room air conditioners. Variants of conventional spiral rifling have been developed, but they have not been shown to be more effective than the rifling which has become standard for tubes used in all air conditioning applications. DOE is not aware of any other improved tube technology that can make further improvements in heat exchanger performance for room air conditioners. Hence, DOE did not further analyze this technology.

DOE did consider use of smaller diameter tubes in the engineering analysis, especially for use with R-410A refrigerant.

5.2.2.3 Hydrophilic-film coating on fins

During interviews conducted during the preliminary analysis phase, manufacturers indicated that hydrophilic film coatings do improve room air conditioner efficiency. However, they indicated that use of these coatings is standard practice for room air conditioners. Hence, DOE did not further analyze this technology.

5.2.2.4 Spray condensate onto condenser coil

Spraying of condensate onto the condenser coil is currently used in all room air conditioners. DOE questioned manufacturers during interviews about more effective approaches for use of the condensate, but no viable alternatives were identified. DOE measured the condenser fan power impact of the slinger ring on a typical room air conditioner and determined that filling the condensate pan with water and thus initiating slinging action made no noticeable impact on fan power input. The engineering analysis incorporated use of condensate spraying into the energy use analysis. However, in no case was this technology used as the basis for estimates of possible efficiency improvement, since all baseline products were analyzed assuming they already have this feature. The effect of condensate spray on room air conditioner performance was based upon research to determine the effect that water spray had on heat exchanger performance.[2] Hence, DOE did not further analyze this technology.

5.2.2.5 Improved indoor blower and outdoor fan efficiency

The indoor blowers and outdoor fans of current room air conditioners are molded plastic parts with complex geometries. The performance of these blowers and fans has improved as compared to stamped sheet metal fan blades used in the past. DOE expects that there may be potential for incremental improvement in air moving efficiency for some room air conditioners. However, there are no data available which can be used to predict this improvement. During manufacturer interviews, improvement in air moving efficiency through use of better fan blades or blower impellers was not identified as a viable option for improvement in room air conditioner efficiency. Hence, DOE did not further analyze these technologies.

5.2.2.6 Two-speed, Variable-speed, or Modulating-capacity Compressors

Two-speed, variable-speed, or modulating-capacity compressors can increase efficiency over a broad operating range, but they do not inherently increase the efficiency at the room air conditioner rating point. Because the DOE energy test procedure specifies steady-state maximum-capacity conditions for evaluation of active mode efficiency, the speed of a variable-speed compressor would remain at a constant maximum capacity (*e.g.* highest speed) during the test. As a result, there is no opportunity to measure the energy savings that such compressors can provide during part-load conditions, when, instead of cycling at high speed, they operate a reduced capacity to satisfy the load. In fact, the losses associated with the inverter board of a variable-speed compressor would decrease the maximum-capacity energy efficiency ratio (EER). Therefore, DOE did not further analyze this technology in the engineering analysis.

5.2.2.7 Thermostatic or Electronic Expansion Valves

Thermostatic or electronic expansion valves have the capability of maintaining optimum room air conditioner operating parameters over a broad range of operating conditions (outdoor and room temperature levels, during startup transients, and in case of high or low refrigerant charge). However, because the DOE energy test procedure for room air conditioners specifies steady state operating conditions, the benefit of these technologies will not be measured by the test. The design of a capillary expansion device can be adjusted to provide optimum operating conditions for the steady-state test. Therefore, DOE did not consider these technologies further in the engineering analysis.

5.2.2.8 Thermostatic Cyclic Controls

Advanced thermostatic cyclic controls would be designed to control room air conditioner operation if the load is less than the room air conditioner capacity. The DOE energy test procedure, however, measures room air conditioner efficiency at full-capacity steady conditions. Hence, the test procedure cannot measure the efficiency benefits of alternative thermostatic controls which might improve control of the cycling (or modulation for variable capacity units) of the room air conditioner. Therefore, DOE did not further consider this technology in the engineering analysis.

5.3 PRODUCT CLASSES ANALYZED

DOE separated residential clothes dryers and room air conditioners into product classes. Because DOE formulated a separate energy conservation standard for each product class, the criteria for separation into different classes are: (1) type of energy used (natural gas or electricity), and (2) capacity or other performance-related features such as those that provide utility to the consumer, or others deemed appropriate by the Secretary that would justify the establishment of a separate energy conservation standard. (42 United States Code (U.S.C.) 6295 (q))

For residential **clothes dryers**, DOE considered four product classes for vented and two product classes for ventless clothes dryers, as shown in Table 5.3.1. This is a new analytical structure for clothes dryers, recognizing the unique utility that ventless clothes dryers offer to consumers. (Previously, DOE has described ventless clothes dryers as condensing clothes dryers. The new designation reflects the actual consumer utility (*i.e.,* no external vent required) and the potential market availability of vented clothes dryers that also condense). Another new entry with unique utility is the combination washer/dryer (*i.e.*, a device which washes and then dries clothes in the same basket/cavity in a combined cycle). Combination washer/dryers are suitable for space-constrained environments (*e.g.*, apartments, recreational vehicles), and all products of this type appear to utilize ventless operation. Thus, like other ventless clothes dryers, such combination washer/dryers can be installed in locations where venting dryers would be precluded due to venting restrictions. As discussed in chapter 3 of this TSD, DOE recently adopted amendments to the clothes dryer test procedure in the January 2011 TP Final Rule to include provisions for testing ventless clothes dryers, thus allowing the consideration of ventless product classes. The amendments for ventless clothes dryers are discussed in more detail in chapter 3 of this TSD.

Table 5.3.1 Residential Clothes Dryer Product Classes

Vented dryers
1. Electric, Standard (4.4 cubic feet (ft^3) or greater capacity)
2. Electric, Compact (120 volts (v)) (less than 4.4 ft^3 capacity)
3. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)
4. Gas
Ventless dryers
5. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)
6. Electric, Combination Washer/Dryer

For **room air conditioners**, amendments to the Energy Policy and Conservation Act (EPCA) of 1975, Pub. L. 94-163, (42 U.S.C. 6291–6309) in the National Appliance Energy Conservation Act of 1987 (NAECA), Pub. L. 100-12, initially specified 12 product classes for products designed for single- or double-hung window installation or through-the-wall installation and based on the following criteria: (1) cooling capacity; (2) the presence of louvered sides (LS); and (3) the capability of reverse cycle (*i.e.*, the unit can function as a heat pump). (42 U.S.C. 6295(c)(1)) Capacity is measured in British Thermal Units (Btu) per hour (h) (Btu/h). In the final rule published in the *Federal Register* on September 24, 1997, DOE established an updated set of performance standards (effective October 1, 2000) which included four additional product classes.[a]

As detailed in chapter 3 of this TSD, DOE is establishing in this final rule four new product classes by splitting existing product classes 5 and 8 into two product classes each. Table 5.3.2 lists the 18 resulting product classes for room air conditioners. See chapter 3 for additional discussion of the creation of these new product classes.

Based on DOE's estimate that higher-capacity units may be constrained by space limitations in their ability to incorporate design options that could raise energy efficiency, and the assumption that the increments in energy efficiency among the other product classes are well-defined by the increments in their associated minimum efficiency standards, DOE conducted a full analysis of product classes 1, 3, 5, and 8 during the preliminary analysis. For this final rule, DOE conducted full analyses of product classes 1, 3, 5A, 5B, 8A, and 8B. Product classes 1, 3, 5A, and 5B span the range of capacities of room air conditioners without reverse cycle and with louvered sides. Product classes 8A and 8B are intermediate-capacity product classes for room air-conditioners without reverse cycle and without louvered sides. These two product classes represent the

[a] DOE divided the product class covering units with reverse cycle and with louvered sides into units of capacity less than 20,000 Btu/h and units 20,000 Btu/h or more. DOE split the product class covering units with reverse cycle and without louvered sides into units of capacity less than 14,000 Btu/h and units 14,000 Btu/h or more. In addition, DOE established two new product classes for units that are designed to be installed in casement-slider and casement-only windows. Due to the size constraints imposed by casement windows, casement units are small in size and typically deliver 5,000 to 10,000 Btu/h in cooling capacity.

majority of shipments of products without reverse cycle without louvered sides (see Figure 3.15.10 in chapter 3). DOE then grouped each of the remaining 12 product classes with an analyzed product class that provided the best representation of cost effectiveness for improving its efficiency. This grouping is discussed in greater detail in section 5.6.2.11.

Table 5.3.2 Room Air Conditioner Product Classes

Without reverse cycle and with louvered sides
1. Less than 6,000 Btu/h
2. 6,000 to 7,999 Btu/h
3. 8,000 to 13,999 Btu/h
4. 14,000 to 19,999 Btu/h
5A. 20,000 to 27,999 Btu/h
5B. 28,000 Btu/h or more
Without reverse cycle and without louvered sides
6. Less than 6,000 Btu/h
7. 6,000 to 7,999 Btu/h
8A. 8,000 to 10,999 Btu/h
8B. 11,000 to 13,999 Btu/h
9. 14,000 to 19,999 Btu/h
10. 20,000 Btu/h or more
With reverse cycle
11. With louvered sides and less than 20,000 Btu/h
12. Without louvered sides and less than 14,000 Btu/h
13. With louvered sides and 20,000 Btu/h or more
14. Without louvered sides and 14,000 Btu/h or more
Casement
15. Casement-Only
16. Casement-Slider

5.4 EFFICIENCY LEVELS

5.4.1 Baseline Units

DOE selected baseline units as reference points for each product class, against which DOE measured changes resulting from energy conservation standards. The baseline unit in each product class represents the basic characteristics of equipment in that class. Typically, a baseline unit is a unit that just meets current required energy conservation standards and provides basic consumer utility.

DOE used the baseline units in the engineering analysis and the LCC and PBP analysis. To determine energy savings and changes in price, DOE compared each higher-energy-efficiency or lower-energy-efficiency design option with the baseline unit.

As discussed in chapter 3 of this TSD, EPCA requires that the test procedures for clothes dryers and room air conditioners be amended to include measurement of standby mode and off mode power, except where current test procedures fully address such energy consumption or such a procedure is technically infeasible. EPCA also requires that any final rule establishing or revising a standard for a covered product, adopted after July 1, 2010, shall incorporate standby mode and off mode energy use into a single amended or new standard, if feasible. If not feasible, the Secretary shall prescribe within the final rule a separate standard for standby mode and off mode energy consumption. (42 U.S.C. 6295(gg)) As discussed in chapter 3 of this TSD, DOE published the January 2011 TP Final Rule in which it amended the test procedures to include testing methods for measuring standby and off mode energy use for clothes dryers and room air conditioners. As part of the January 2011 TP Final Rule, DOE adopted new methods to calculate clothes dryer and room air conditioner standby and off mode energy use and new measures of energy efficiency (Combined Energy Factor (CEF) and Combined Energy Efficiency Ratio (CEER), respectively) that integrate standby and off mode energy use with the active mode energy use for both products. As a result, the engineering analysis and the energy conservation standards for clothes dryers and room air conditioners are based on these integrated metrics (CEF and CEER). The CEER is identical to the Integrated Energy Efficiency Ratio (IEER) metric used in the preliminary analysis documents, but renamed to avoid confusion with an existing industry standard. The “inactive” mode of this metric is now referred to simply as the standby mode. The CEF differs from the IEF metric previously used, in that it is based on a different number of annual cycles for the active mode analysis.

Test data based on CEF and CEER, as defined in the January 2011 TP Final Rule, are not available for any products. As a result, baseline units for these metrics are defined using the baseline efficiency characteristics of products using current efficiency metrics and an understanding of the typical energy use of the products in standby and off modes. The following sections discuss active mode, standby/off mode(s), and integrated metric characteristics for baseline products.

5.4.1.1 Active Modes

The current minimum energy conservation standards for residential **clothes dryers**, as measured by energy factor (EF) in pounds (lb) per kilowatt-hour (kWh) under the previous DOE clothes dryer test procedure (found at 10 Code of Federal Regulations (CFR) part 430, subpart B, appendix D), became effective on May 14, 1994. Table 5.4.1 sets forth the standards for the four vented clothes dryer product classes. (10 CFR part 430.32(h)(2)) DOE used these existing energy conservation standards to characterize the baseline active mode unit efficiency for each of the vented product classes. DOE estimated baseline efficiencies for ventless dryers based upon testing it conducted on representative units, using the previous DOE clothes dryer test procedure without the exhaust simulator.

Table 5.4.1 Clothes Dryer Baseline Active Mode Unit Efficiencies

Product Class	**EF** *(lb/kWh)*
Vented dryers	
1. Electric, Standard (4.4 ft^3 or greater capacity)	3.01
2. Electric, Compact (120 v) (less than 4.4 ft^3 capacity)	3.13
3. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.90
4. Gas	2.67
Ventless dryers	
5. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.37
6. Electric, Combination Washer/Dryer	1.95

In addition to adopting provisions for the measurement of standby mode and off mode power use, as discussed above, DOE also adopted amendments to the clothes dryer test procedure in the January 2011 TP Final Rule concerning the active mode. In particular, DOE adopted amendments to include provisions for the testing of ventless products. The amendments also included the following changes to reflect the current usage and capabilities of products to: (1) change the clothes dryer use cycles per year from 416 to 283, (2) change the initial remaining moisture content (RMC) of clothes dryer loads from 70 ± 3.5 percent to 57.5 ± 3.5 percent, and (3) change the clothes dryer test load size from 7.00 ± .07 pounds (lbs) to 8.45 ± .085 lbs for standard-size clothes dryers. In addition, the January 2011 TP Final Rule also amends the DOE clothes dryer test procedure to: (1) revise the detergent specifications for test cloth preconditioning due to obsolescence of the detergent specified in the test procedure, (2) revise the water temperature for test load preparation from 100 degrees Fahrenheit (°F) ± 5 °F to 60 °F ± 5 °F, (3) update references to industry test standards, (4) eliminate an unnecessary reference to an obsolete industry test standard, (5) clarify the required gas supply conditions for testing gas clothes dryers (6) amend the provisions for measuring the drum capacity, (7) amend the provisions for the application of the field use factor for automatic cycle termination, (8),add the calculations of EF and CEF to 10 CFR part 430, subpart B, appendix D1. 76 FR 972, 993–1020 (Jan. 6, 2011).

EPCA requires that DOE must determine to what extent, if any, the proposed test procedure would alter the measured energy efficiency of any covered product as determined under the existing test procedure. (42 U.S.C. 6293(e)(1)) If DOE determines that the amended test procedure would alter the measured efficiency of a covered product, DOE must amend the applicable energy conservation standard accordingly. In determining the amended energy conservation standard, DOE shall measure, pursuant to the amended test procedure, the energy efficiency, energy use, or water use of a representative sample of covered products that minimally comply with the existing standard. The average of such energy efficiency, energy use, or water use levels determined under the amended test procedure shall constitute the amended energy conservation standard for the applicable covered products. (42 U.S.C. 6293(e)(2)) EPCA also states that models of covered products in use before the date on which the amended energy conservation standard becomes effective (or revisions of such models that come into use after such date and have the same energy efficiency, energy use, or water use characteristics) that comply with the energy conservation standard applicable to such covered products on the day before such date shall be deemed to comply with the amended energy conservation standard. (42 U.S.C. 6293(e)(3)) DOE notes that these EPCA requirements apply only when there is no concurrent energy conservation standards rulemaking. However, DOE has adjusted the measured efficiency values as part of this rulemaking, consistent with these requirements.

As part of the January 2011 TP Final Rule, DOE conducted testing on a sample of 17 representative clothes dryers to evaluate the effects of the amendments to the clothes dryer test procedure on the measured EF. DOE tested these units according to the amended clothes dryer test procedure in the January 2011 TP Final Rule, conducting up to three tests for each test unit and averaging the results. The results from this testing are shown below in Table 5.4.2. DOE noted in its testing that the amendments to the initial RMC, water temperature for test load preparation, and load size had an effect on the measured EF as compared to the existing test procedure. For vented electric standard-size clothes dryres, the measured EF increases by an average of about 20.1 percent as a result of the amendments to the test procedure. For vented gas clothes dryers, the measured EF increased by an average of about 19.8 percent. For vented electric compact-size 120V and 240V clothes dryers, the measured EF increased by an average of about 15.6 and 12.8 percent, respectively. For ventless electric compact 240V clothes dryers and ventless electric combination washer-dryers, the measured EF increased by an average of about 13.6 and 11.4 percent, respectively, as compared to the measured EF using the existing test procedure with only the amendments for ventless clothes dryers (without the changes to the initial RMC, water temperature for test load preparation, etc.). DOE noted that the increase in measured EF is greater for the standard-size products (*i.e.*, vented electric standard-size and vented gas dryers) than for compact-size products due to the additional amendments to increase the test load size for standard-size products. 76 FR 972, 1022–28 (Jan. 6, 2011).

Table 5.4.2 DOE Test Results to Evaluate the Effects of the Test Procedure Amendments on Measured EF

Test Unit		Average EF (lb/kWh)		% Change
		Previous Test Procedure (Appendix D)	Amended Test Procedure (Appendix D1)	
Vented Electric Standard	Unit 1	3.07	3.69	20.4%
	Unit 2	3.14	3.77	19.5%
	Unit 3	3.20	3.83	19.6%
	Unit 4	3.28	3.92	19.4%
	Unit 5	3.24	3.96	22.5%
	Unit 6	3.12	3.72	19.1%
Vented Gas	Unit 7	2.78	3.36	20.6%
	Unit 8	2.83	3.40	19.9%
	Unit 9	2.85	3.42	20.2%
	Unit 10	2.80	3.37	20.5%
	Unit 11	2.98	3.50	17.6%
Vented Electric Compact (240V)	Unit 12	3.19	3.56	11.4%
	Unit 13	2.93	3.35	14.2%
Vented Electric Compact (120V)	Unit 14	3.23	3.74	15.6%
Ventless Electric Compact (240V)	Unit 15	2.37	2.69	13.6%
Ventless Electric Combo Washer-Dryer	Unit 16	2.01	2.27	12.5%
	Unit 17	2.50	2.76	10.3%

DOE applied these separate average percentage increases in the measured EF based on the test procedure amendments discussed above for each product class to the efficiency levels presented above in Table 5.4.1. Table 5.4.3 shows the revised baseline efficiency levels values for each product class.

Table 5.4.3 Clothes Dryer Baseline Active Mode Unit Efficiencies Revised for Test Procedure Amendments

Product Class	**EF** *(lb/kWh)*	
	Previous Test Procedure	**Amended Test Procedure**
Vented dryers		
7. Electric, Standard (4.4 ft^3 or greater capacity)	3.01	3.62
8. Electric, Compact (120 v) (less than 4.4 ft^3 capacity)	3.13	3.62
9. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.90	3.27
10. Gas	2.67	3.20
Ventless dryers		
11. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.37	2.69
12. Electric, Combination Washer/Dryer	1.95	2.17

The minimum energy conservation standards for **room air conditioners**, as measured by EER in Btu/h per watt (W), became effective on October 1, 2000. Table 5.4.4 sets forth the current minimum energy conservation standards for the 16 room air conditioner product classes. (10 CFR Part 430.32(b)) DOE used the existing energy conservation standards to characterize the baseline active mode unit efficiency for each product class, including using the existing standards of the currently still combined product classes for classes that DOE split in this rulemaking. As mentioned in section 5.3, DOE fully analyzed only product classes 1, 3, 5A, and 5B (room air conditioners without reverse cycle and with louvered sides, with capacities of less than 6,000 Btu/h; 8,000 to 13,999 Btu/h; 20,000 to 27,999 Btu/h; and 28,000 Btu/h or more, respectively), and product classes 8A and 8B (room air conditioners without reverse cycle and without louvered sides, with capacities of 8,000 to 10,999 Btu/h; and 11,000 to 13,999 Btu/h, respectively) and subsequently extended the analyses to the other product classes.

Table 5.4.4 Room Air Conditioner Baseline Active Mode Unit Efficiencies

Product Class	**EER** *(Btu/h-W)*
Without reverse cycle and with louvered sides	
1. Less than 6,000 Btu/h	9.7
2. 6,000 to 7,999 Btu/h	9.7
3. 8,000 to 13,999 Btu/h	9.8
4. 14,000 to 19,999 Btu/h	9.7
5A. 20,000 to 27,999 Btu/h	8.5*
5B. 28,000 Btu/h or more	8.5*
Without reverse cycle and without louvered sides	
6. Less than 6,000 Btu/h	9.0
7. 6,000 to 7,999 Btu/h	9.0
8A. 8,000 to 10,999 Btu/h	8.5*
8B. 11,000 to 13,999 Btu/h	8.5*
9. 14,000 to 19,999 Btu/h	8.5
10. 20,000 Btu/h or more	8.5
With reverse cycle and with louvered sides	
11. Less than 20,000 Btu/h	9.0
12. 20,000 Btu/h or more	8.5
With reverse cycle and without louvered sides	
13. Less than 14,000 Btu/h	8.5
14. 14,000 Btu/h or more	8.0
Casement	
15. Casement-Only	8.7
16. Casement-Slider	9.5

* Products of these two pairs of classes are covered in the current energy conservation standards under their "combined" classes of the current standards.

5.4.1.2 Standby Mode and Off Mode

In the January 2011 TP Final Rule, DOE adopted clothes dryer and room air conditioner test procedure amendments to measure standby and off mode energy use. Among other provisions, "active mode," "standby mode," and "off mode" are defined based on the definitions in IEC Standard 62301 Second Edition, Committee Draft for Vote (CDV).

> "Active mode" is defined as a mode which "includes product modes where the energy using product is connected to a mains power source, has been activated and provides one or more main functions."
>
> "Standby mode" is defined as a mode category which "includes any product modes where the energy using product is connected to a mains power source and offers one or more of the following user oriented or protective functions which may persist for an indefinite time:
>
> - To facilitate the activation of other modes (including activation or deactivation of active mode) by remote switch (including remote control), internal sensor, timer;
> - Continuous function: information or status displays including clocks;
> - Continuous function: sensor-based functions."
>
> With the additional clarification that "a timer is a continuous clock function (which may or may not be associated with a display) that provides regular scheduled tasks (*e.g.*, switching) and that operates on a continuous basis."
>
> "Off mode" is defined as a mode which "includes any product modes where the energy using product is connected to a mains power source and is not providing any standby mode or active mode function and where the mode may persist for an indefinite time. An indicator that only shows the user that the product is in the off position is included within the clasification of off mode." 76 FR 972, 980–985 (Jan. 6, 2011).

In addition, the amendments provide that if power consumption drops from a higher-power state to a lower-power state in a given mode, as discussed in Section 5, Paragraph 5.1, note 1 of IEC Standard 62301, to allow sufficient time for the product to reach the lower power state before proceeding with the test measurement. 76 FR 972, 985–986 (Jan. 6, 2011).

DOE measured standby and off mode energy use of residential **clothes dryers** in its sample of reverse-engineered units. (See section 5.6.1.3 for a discussion of the reverse engineering test sample, methodology, and results.) The results of the standby and off mode measurements are shown in Table 5.4.5 below. The compact (240 V) ventless and one electric standard vented clothes dryer in the test sample were unable be measured for standby/off mode power consumption because components energized in standby and off mode were powered off 240 V line power, which could not be accommodated by the power meter used by DOE. Additionally, DOE was unable to obtain any test units for electric compact (120 V) vented clothes dryers, so no data is presented for this product class.

Standby and off modes were determined for clothes dryers by observing unit function and power consumption for various operating states other than when the dryer was actively drying or tumbling the clothing. The operating conditions identified for the clothes dryers which are potential standby and off modes included (1) the unit plugged in, but the power switch turned off; (2) the unit plugged in and powered on, but no drying cycle setting selected; (3) the unit plugged in and powered on, with a "normal" setting selected but the drying cycle not started; and (4) the active cycle completed. DOE did not measure power consumption during a delay start condition because none of the clothes dryers in DOE's test sample were equipped with such a feature. For some clothes dryers in the test sample with electronic controls, DOE observed that at the completion of the active cycle, power consumption initially was measured at a higher level, then after a period of inactivity of typically several tens of seconds, would drop to a lower level. After another period of inactivity of typically several minutes, these dryers then changed to a state with even lower power consumption, in which all displays were turned off and the on/off "soft" power switch reset to the "off" condition. In this state, power consumption was the same as when the unit was initially plugged in but not powered on. In other cases, at the completion of the active cycle, the power consumption initially was measured at a higher level, then after a period of inactivity of typically tens of seconds, would drop to a lower level for which only a single light emitting diode (LED) was illuminated to indicate that the cycle was complete. This mode persisted until the dryer door was opened, at which point the LED turned off and the dryer reverted to an even lower power state in which all displays were turned off and the on/off "soft" power switch reset to the "off" condition. As for the previously discussed case, in this state, the power consumption was the same as for when the unit was initially plugged in but not powered on. Since, for the clothes dryers equipped with electronic controls, the unit would only be powered on in anticipation of starting a drying cycle and would revert to the lowest power consumption state after a period of several minutes after the cycle completed or after the clothes have been removed from the drum, DOE believes that the lowest power state represents standby/off mode energy use. Further, since DOE observed that all clothes dryers with displays deactivate them in this lowest power state but include a soft switch for initiating active mode, such units would be operating in a standby mode rather than in off mode. In contrast, clothes dryers with electromechanical controls do not consume any power when the unit is plugged in and not in active mode or once the active cycle has completed, and can thus be considered to operate in off mode. DOE also noted that for operating conditions (2) and (3) defined above, after a period of user inactivity (generally between 5 and 10 minutes), the display turns off and the on/off "soft" power switch resets to the "off' condition, reverting the clothes dryer to the lower power consumption state.

Table 5.4.5 summarizes the power consumption measurements in standby/off mode for each of the clothes dryers in the DOE test sample for which standby power could be measured. Review of this data, along with information on design options obtained during reverse-engineering activities, resulted in DOE proposing a level of 2.0 W for baseline power consumption in standby/off mode. This value is based on a maximum measured input power of 1.51 W for a unit with electronic controls, and thus which provides the consumer utility of a display. The model in the DOE test sample with this standby power consumption, however, was observed to incorporate a switching power supply, which DOE identified as a design option to reduce standby power consumption. In order to define the baseline level for an assumed clothes dryer that uses a conventional power supply, DOE increased the 1.51 W by the estimated change in standby power associated with changing from a conventional to switching power supply. DOE also measured standby power of approximately 0.7 W for other clothes dryers equipped with electronic controls and displays that were observed to differ only by having fewer available cycle settings. Because DOE does not intend to restrict consumer utility associated with the number of different cycles, the baseline was chosen to allow the maximum number of settings.

Table 5.4.5 Clothes Dryer Standby and Off Mode Power Input Measurements

Product Class	Test Unit	EF *(lb/kWh)*	Control Type	Power Input *(W)*	Mode
Vented Electric, Standard	1	3.06	Electromechanical	0.00	Off
	2	3.10	Electromechanical	0.00	Off
	3	3.15	Electronic	0.69	Standby
	4	3.20	Electromechanical	0.00	Off
	5	3.40	Electromechanical		Standby
Vented Electric, Compact (120 V)	6	2.98	Electromechanical	0.00	Off
Vented Gas	7	2.67	Electromechanical	0.00	Off
	8	2.76	Electronic	0.69	Standby
	9	2.8	Electronic	1.51	Standby
	10	3.00	Electronic	0.08	Standby
Ventless Combination Washer/Dryer	11	-	Electronic	0.83	Standby

DOE measured standby/off mode energy use of **room air conditioners** in order to determine the appropriate energy use baseline for these modes. The results of these measurements are shown in Table 5.4.6 below. Note that products with electronic controls were capable of operation in standby mode, as defined in the January 2011 TP Final Rule, while products with electromechanical controls were capable of operation in off mode. For simplicity, DOE defined baseline characteristics for room air conditioners assuming use of electronic controls. Based on the test data, DOE established a baseline standby/off mode power consumption level of 1.4 W. This power input level was higher than all but four of the electronic-control products tested, and the highest power measurement was only 13.5 percent higher than this level.

Table 5.4.6 Room Air Conditioner Standby and Off Mode Power Input Measurements

Product Class	Capacity *(Btu/h)*	EER *(Btu/h-W)*	Control Type	Power Input *(W)*	
				Standby Mode	Off Mode
1	5,000	9.7	Electronic	1.59	
1	5,200	9.7	Electromechanical		0.20
1	5,200	10.7	Electronic	1.28	
1	5,200	11	Electronic	1.46	
3	11,800	11.8	Electronic	1.30	
3	11,800	10.8	Electronic	0.68	
3	12,000	9.8	Electronic	1.36	
3	8,400	11.4	Electronic	1.34	
3	8,000	9.8	Electronic	0.91	
3	8,000	10.8	Electronic	1.40	
3	12,000	9.5*	Electronic	1.21	
5	24,500	8.5	Electronic	0.74	
5	24,000	9.4	Electronic	1.404	
8	8,000	10.5	Electronic	1.27	
8	8,000	9.4	Electronic	1.44	
8	8,000	9.6	Electronic	1.52	
8	11,600	9.5	Electromechanical		0.03
8	11,500	8.5	Electromechanical		0.03
11	11,600	9.5	Electromechanical		0.03
16	8,000	9.5	Electronic	1.41	

*This product was advertised as being through-the-wall (*i.e.* product class 8), but it has louvered sides and no way to allow air flow into the condenser fan intake if the louvers were blocked off by a wall sleeve.

5.4.1.3 Integrated Efficiency

For the preliminary analysis, DOE based its analysis for **residential clothes dryers** on the Integrated Energy Factor (IEF) metric proposed as an alternative option in the December 2008 TP NOPR. Baseline IEF levels were determined from the baseline EF and standby energy use as discussed in sections 5.4.1.1 and 0. The IEF is calculated as the clothes dryer test load weight in lb divided by the sum of “active mode” per-cycle energy use and “standby mode” per-cycle energy use in kWh. As noted above, inactive mode was defined in the December 2008 NOPR as a standby mode other than delay start mode or cycle finished mode that facilitates the activation of active mode by remote switch (including remote control), internal sensor, or timer, or that provides continuous status display. This is the standby mode measured under the discussion in section 0 above. The per-cycle energy consumption associated with this standby mode for residential clothes dryers is calculated assuming 416 clothes dryer cycles in a year and 8,620 hours associated with standby mode. Table 5.4.7 shows the baseline IEF for each residential clothes dryer product class.

Table 5.4.7 Baseline Clothes Dryer IEF

Product Class	EF (Previous Test Procedure) *(lb/kWh)*	Standby Power *(W)*	IEF *(lb/kWh)*
Vented dryers			
1. Electric, Standard (4.4 ft^3 or greater capacity)	3.01	2.0	2.96
2. Electric, Compact (120 v) (less than 4.4 ft^3 capacity)	3.13	2.0	3.00
3. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.90	2.0	2.79
4. Gas	2.67	2.0	2.63
Ventless dryers			
5. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.37	2.0	2.29
6. Electric, Combination Washer/Dryer	1.95	2.0	1.90

As discussed above, DOE recently published the January 2011 TP Final Rule in which it adopted clothes dryer test procedure amendments to measure standby and off mode energy use. Therefore, DOE based its analysis for this final rule for residential clothes dryers on the CEF metric adopted in the January 2011 TP Final Rule. Baseline CEF levels were determined from the baseline EF under the amended test procedure (as discussed above in section 5.4.1.1) and the same standby power levels analyzed for the preliminary analysis, as discussed above in section 5.4.2.2. The per-cycle energy consumption associated with standby mode for residential clothes dryers is calculated assuming 283 clothes dryer cycles in a year[b] and 8,620 hours associated with standby mode. Table 5.4.8 shows the baseline CEF for each residential clothes dryer product class.

Table 5.4.8 Baseline Clothes Dryer CEF

Product Class	EF (Amended Test Procedure) *(lb/kWh)*	Standby Power *(W)*	CEF *(lb/kWh)*
Vented dryers			
7. Electric, Standard (4.4 ft^3 or greater capacity)	3.62	2.0	3.55
8. Electric, Compact (120 v) (less than 4.4 ft^3 capacity)	3.62	2.0	3.43
9. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	3.27	2.0	3.12
10. Gas	3.20	2.0	3.14
Ventless dryers			
11. Electric, Compact (240 v) (less than 4.4 ft^3 capacity)	2.69	2.0	2.55
12. Electric, Combination Washer/Dryer	2.17	2.0	2.08

For the preliminary analysis, DOE based its analysis for **room air conditioners** on the IEER metric proposed as an alternative option in the December 2008 NOPR. As discussed above, DOE recently published the January 2011 TP Final Rule, in which it modified the name of the integrated metric to CEER to avoid conflict with another pre-existing use of the term

[b] DOE revised the number of active mode cycles per year in the January 2011 TP Final Rule from 416 to 283 cycles per year based on analysis of more recent consumer usage data.

IEER. DOE determined baseline CEER levels from the baseline EER and standby energy use as discussed in sections 5.4.1.1 and 0. CEER is equal to capacity times active mode hours (equal to 750) divided by the sum of active mode annual energy use and standby mode annual energy use, as defined above. This is the standby mode measured under the discussion in section 0 above. The number of hours associated with this standby mode for room air conditioners is 5,115 hours per year.

Because CEER depends on capacity, calculating its baseline value for a product class requires specification of that capacity. For the four product classes and the capacities analyzed in detail for the preliminary analysis, the baseline CEERs are as indicated in Table 5.4.9 below.

Table 5.4.9 Baseline Room Air Conditioner CEER for Analyzed Product Classes

Product Class	Capacity *(Btu/h)*	EER *(Btu/h-W)*	Standby Power *(W)*	CEER *(Btu/h-W)*
1	5,000	9.7	1.4	9.52
3	8,000	9.8	1.4	9.69
3	12,000	9.8	1.4	9.72
5A	24,000	8.5	1.4	8.47
5B	28,000	8.5	1.4	8.48
8A	8,000	8.5	1.4	8.41
8B	12,000	8.5	1.4	8.44

5.4.2 Incremental Efficiency and Standby Levels

5.4.2.1 Active Mode

For the majority of the product classes presented in section 5.3, DOE analyzed several efficiency levels and obtained incremental cost data at each of these levels. Table 5.4.10 through Table 5.4.16 provide efficiency levels and the reference source of each level for each of the products under consideration. For most of the product classes, the highest efficiency level was identified based on a review of available product literature for products commercially available (this applied for gas vented clothes dryers and all room air conditioner product classes). For electric vented and ventless clothes dryers, the maximum levels identified in Table 5.4.10 and Table 5.4.11 are based on available research and product literature on heat pump clothes dryers as well as discussions with manufacturers.

As part of the preliminary analysis for **residential clothes dryers**, DOE considered four efficiency levels beyond the baseline efficiency level for electric standard vented clothes dryers and electric compact (120V and 240V) vented clothes dryers, and three efficiency levels for the gas vented product class, as listed in Table 5.4.10. These levels were derived primarily from data contained within the California Energy Commission (CEC) and Natural Resources Canada (NRCan) product databases. For gas clothes dryers, the highest efficiency level (which is the maximum technologically feasible (max-tech) level) is based on the value proposed in the framework document that was based on data contained in the CEC product database. AHAM submitted aggregated incremental manufacturing cost data in support of this max-tech efficiency level for vented gas clothes dryers. As discussed in section 5.6.1.5, multiple manufacturers stated during interviews that the current maximum efficiency that is listed for vented gas clothes dryers in the CEC product database is not achievable. Also, as discussed in section 0, DOE testing of the "maximum-available" gas clothes dryer determined that this unit did not achieve the rated efficiency. For these reasons, DOE proposed for the preliminary analysis to use the vented gas clothes dryer max-tech value for which AHAM submitted aggregated incremental manufacturing costs. This max-tech level was supported by multiple manufacturers during interviews. DOE also added two levels to fill the gap between the baseline and the max-tech for this product class. Since no data was available from either database for electric compact (120 V) clothes dryers, efficiency levels above the baseline for this product class were obtained by scaling the efficiency levels for electric standard units by the ratio of the baseline efficiencies. For electric standard and electric compact (240V) clothes dryers, the max-tech level corresponds to the efficiency improvement associated with incorporating heat pump technology, which was based upon manufacturer interviews and available research on heat pump dryers, while the three gap fill levels are derived from certification data. Some of these efficiency levels were changed from those proposed in the framework document, based on comments from interested parties, manufacturer interviews, and more recent certification data. Because DOE only recently amended the clothes dryer test procedure, the efficiency levels developed for the preliminary analysis were based on EF using the previous DOE clothes dryer test procedure. Table 5.4.10 below shows the efficiency level values for each vented clothes dryer product class proposed in the preliminary analysis.

Table 5.4.10 Vented Clothes Dryer Active Mode Efficiency Levels – Preliminary Analysis

Level	**Efficiency Level Description**	**Efficiency Level (EF)** *(lb/kWh)*			
		Electric Standard	**Electric Compact (120V)**	**Electric Compact (240V)**	**Gas**
Baseline	DOE Standard	3.01	3.13	2.90	2.67
1	Gap Fill	3.10	3.22*	2.98	2.75
2	Gap Fill	3.16	3.29*	3.09	2.85
3	Gap Fill/Maximum Available	3.40	3.54*	3.20	3.02 (max-tech)
4	Max-Tech	4.51	4.70*	4.35	

* Estimated by scaling from electric standard clothes dryer efficiency levels.

For ventless clothes dryers, DOE considered three efficiency levels above the baseline for both electric compact (240 V) and electric combination washer/dryer product classes for the preliminary analysis. For ventless electric compact (240 V) clothes dryers, DOE estimated efficiency level (EL) 1 using methodology based on a waiver DOE provided to Miele, Inc. (Miele) for its condenser clothes dryer. In that waiver, Miele voluntarily agreed to maintain the performance of its condenser clothes dryer to within 82.5 percent of the existing energy conservation standard for electric standard clothes dryers. 60 FR 9332 (Feb. 17, 1995). That same percentage was applied to the existing energy conservation standard for electric compact

(240 V) vented clothes dryers (EF = 2.90) to obtain an EF of 2.39 for electric compact (240 V) ventless clothes dryers. A gap-fill level for EL 2 was derived based upon test data from the National Institute of Standards and Technology (NIST). For ventless electric combination washer/dryers, EL 1 was based upon the efficiency improvement credit for incorporating automatic termination control per the DOE test procedure. A gap-fill level for EL 2 was derived using the efficiency improvement from design changes to reach EL 3[c] for electric standard dryers, scaled based upon the inherently lower efficiency of combination washer/dryers. The max-tech for both ventless electric compact (240 V) and combination washer/dryers was derived from the efficiency improvements associated with heat pump technology, as described above for electric standard dryers. DOE recognizes there is some uncertainty associated with the values based upon data from product databases, as it is unclear what test procedure was used to measure EF. As discussed above, because DOE only recently amended the clothes dryer test procedure, the efficiency levels developed for the preliminary analysis were based on EF using the previous DOE clothes dryer test procedure without the exhaust simulator, as discussed above in section 5.4.1.1. Table 5.4.11 below shows the efficiency level values for each ventless clothes dryer product class proposed in the preliminary analysis.

Table 5.4.11 Ventless Clothes Dryer Active Mode Efficiency Levels – Preliminary Analysis

Level	Efficiency Level Description	Efficiency Level (EF) *(lb/kWh)*	
		Electric Compact (240 V)	**Electric Combination Washer/Dryer**
Baseline	DOE Test Data	2.37	1.95
1	Gap Fill	2.39*	2.21
2	Gap Fill	2.59†	2.42
3	Max Tech	3.55	3.32

*Determined by scaling the existing Federal standard for vented electric compact (240V) clothes dryers based on Miele's voluntary plan to maintain its condenser clothes dryer EF within 82.5 percent of the existing non-condenser clothes dryer standard. 60 FR 9332.
† Based on NIST test data.[3]

As discussed above in section 5.4.1.1, DOE conducted product testing in order to convert the EF values for each vented clothes dryer product class measured under the previous DOE clothes dryer test procedure to EF values measured under the amended test procedure. As presented above in section 5.4.1.1, DOE test results showed that the measured EF according to the amended test procedure resulted in an average increase of about 20.1 percent for vented electric standard clothes dryers. For vented gas clothes dryers, the measured EF increased by an average of about 19.8 percent. For vented electric compact-size 120V and 240V clothes dryers, the measured EF increased by an average of about 15.6 and 12.8 percent, respectively. DOE applied these results for each product class to adjust the active mode efficiency levels to account for the amendments to the DOE clothes dryer test procedure in the January 2011 TP Final Rule. In addition, DOE revised the active mode efficiency level 1 for vented electric standard clothes

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[c] The design changes associated with EL 2 for electric standard clothes dryers are not technologically feasible for combination washer/dryers.

dryers and vented gas clothes dryers from 3.10 EF to 3.11 EF and from 2.75 to 2.76 EF, respectively, based on discussions with manufacturers and the efficiency improvement associated with the design options modeled by DOE, presented in section 5.6.1.3. Table 5.4.12 and Table 5.4.13 below show the revised active mode efficiency level values for each vented clothes dryer product class.

Table 5.4.12 Vented Clothes Dryer Active Mode Efficiency Levels (Vented Electric Standard and Vented Electric Compact (120V))

Level	Efficiency Level Description	Efficiency Level (EF) *(lb/kWh)*			
		Electric Standard		Electric Compact (120V)	
		Previous Test Procedure	Amended Test Procedure	Previous Test Procedure	Amended Test Procedure
Baseline	DOE Standard	3.01	3.62	3.13	3.62
1	Gap Fill	3.11	3.74	3.22	3.72
2	Gap Fill	3.17	3.81	3.29	3.80
3	Gap Fill/Maximum Available	3.40	4.08	3.54	4.09
4	Max-Tech	4.52	5.43	4.70	5.44

Table 5.4.13 Vented Clothes Dryer Active Mode Efficiency Levels (Vented Electric Compact (240V) and Vented Gas)

Level	Efficiency Level Description	Efficiency Level (EF) *(lb/kWh)*			
		Electric Compact (240V)		Gas	
		Previous Test Procedure	Amended Test Procedure	Previous Test Procedure	Amended Test Procedure
Baseline	DOE Standard	2.90	3.27	2.67	3.20
1	Gap Fill	2.98	3.36	2.76	3.31
2	Gap Fill	3.09	3.49	2.86	3.41
3	Gap Fill/Maximum Available	3.20	3.61	3.02 (max-tech)	3.62
4	Max-Tech	4.35	4.91		

For ventless clothes dryers, the preliminary analyses were based on the DOE test procedure with only the proposed amendments for ventless clothes dryers. As discussed above in section 5.4.1.1, DOE also conducted testing according to the final amended test procedure, including changes to the initial RMC, water temperature for test load preparation, etc., which showed that for ventless electric compact 240V clothes dryers and ventless electric combination washer/dryers, the measured EF increased by an average of about 13.6 and 11.4 percent, respectively. DOE similarly applied the percentage increases in the measured EF, developed based on product testing, to the EF values proposed for the preliminary analysis to account for the amendments to the DOE clothes dryer test procedure in the January 2011 TP Final Rule, as discussed above in section 5.4.1.1. Based on discussions with manufacturers and based on the efficiency improvement associated with the design options modeled by DOE (discussed in detail below in section 5.6.1.4), active mode efficiency level 2 for ventless electric combination washer-dryers was revised from 2.59 to 2.47 EF.[d] Table 5.4.14 below shows the revised efficiency level values for each ventless clothes dryer product class.

Table 5.4.14 Ventless Clothes Dryer Active Mode Efficiency Levels

Level	Efficiency Level Description	Efficiency Level (EF) *(lb/kWh)*			
		Electric Compact (240 V)		Electric Combination Washer/Dryer	
		Previous Test Procedure	Amended Test Procedure	Previous Test Procedure	Amended Test Procedure
Baseline	DOE Test Data	2.37	2.69	1.95	2.17
1	Gap Fill	2.39	2.72	2.21	2.46
2	Gap Fill	2.47	2.81	2.30	2.56
3	Max Tech	3.56	4.04	3.32	3.70

For **room air conditioners**, during the preliminary analysis, DOE considered varying numbers of efficiency levels, depending on the product class, as indicated in Table 5.4.15 and Table 5.4.16 below. DOE determined these levels based on the range of efficiency levels associated with products as listed in the CEC, ENERGY STAR, and AHAM product databases and verified to be on sale by a listing on either a manufacturer's website or a retailer's website. DOE added a gap fill efficiency level between the current DOE standard and the ENERGY STAR efficiency level. The maximum available level exceeds the CEE Tier 2 level for product class 1, and matches the CEE Tier 2 level for product class 3. For product classes 5 and 8, the CEE Tier 2 levels are higher than the maximum available product EER, and thus are not included as efficiency levels.

Table 5.4.15 Room Air Conditioner Active Mode Efficiency Levels--Product Classes 1 and 3 – Preliminary Analysis

Level	Efficiency Level Description	EER *(Btu/h-W)*	
		Product Class 1: Without Reverse Cycle, With Louvered Sides, < 6,000 Btu/h	Product Class 3: Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h
Baseline	DOE Standard	9.7	9.8
1	Gap Fill	10.2	10.3
2	Energy Star	10.7	10.8
3	CEE Tier 1	11.2	11.3
4	CEE Tier 2	11.6	11.8
5	Maximum Available*	12.0	

* Based on ENERGY STAR-qualified room air conditioners as of July, 2008 and verification of availability through retailer website searches.

[d] EL 2 was derived using the efficiency improvement from design changes to reach EL 3 for electric standard dryers, scaled based upon the inherently lower efficiency of combination washer/dryers.

Table 5.4.16 Room Air Conditioner Active Mode Efficiency Levels--Product Classes 5 and 8 – Preliminary Analysis

Level	Efficiency Level Description	EER *(Btu/h-W)*	
		Product Class 5: Without Reverse Cycle, With Louvered Sides, ≥ 20,000 Btu/h	**Product Class 8: Without Reverse Cycle, Without Louvered Sides, 8,000 – 13,999 Btu/h**
Baseline	DOE Standard	8.5	8.5
1	Gap Fill	9.0	9.0
2	Energy Star	9.4	9.4
3	CEE Tier 1	9.8	9.8
4	Maximum Available*	10.0	10.8 (8,000 Btu/h) 9.8 (12,000 Btu/h)

* Based on ENERGY STAR-qualified room air conditioners as of July, 2008 and verification of availability through retailer website searches. CEE Tier 2 level is higher than the maximum available EER for these product classes.

For the final rule analysis, DOE again considered varying numbers of efficiency levels, depending on the product class, as indicated in Table 5.4.17 to Table 5.4.18 below. DOE based the max-tech levels on the analysis, rather than the maximum available units. DOE also adjusted the gap-fill levels to provide reasonable increments between successive levels. When possible, DOE selected efficiency levels equivalent to CEE Tier 1 and Tier 2. For example the level following the ENERGY-STAR level matches CEE Tier 1 for product classes 1, 5A, and 5B.

Table 5.4.17 Room Air Conditioner Active Mode Efficiency Levels--Product Classes 1 and 3

Level	Efficiency Level Description	EER *(Btu/h-W)*	
		Product Class 1: Without Reverse Cycle, With Louvered Sides, < 6,000 Btu/h	**Product Class 3:Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h**
Baseline	DOE Standard	9.7	9.8
1	Gap Fill	10.2	10.3
2	Energy Star	10.7	10.8
3	Gap Fill 2	11.2	11.0
4	Gap Fill 3	11.5	11.6
5	Max-Tech	11.8**	12.0

** This level is lower than the max-available efficiency of 12.0 identified by DOE. This reflects the 50 lb product weight limit discussed in section 5.6.2.6.

Table 5.4.18 Room Air Conditioner Active Mode Efficiency Levels--Product Classes 5A and 5B

Level	Efficiency Level Description	EER *(Btu/h-W)*	
		Product Class 5A:Without Reverse Cycle, With Louvered Sides, 20,000-27,999 Btu/h	**Product Class 5B:Without Reverse Cycle, With Louvered Sides, ≥ 28,000 Btu/h**
Baseline	DOE Standard	8.5	8.5
1	Gap Fill 1	9.0	9.0
2	Energy Star	9.4	9.4
3	Gap Fill 2	9.8	9.8
4	Max-Tech	10.2	

Table 5.4.19 Room Air Conditioner Active Mode Efficiency Levels--Product Classes 8A and 8B

Level	Efficiency Level Description	EER *(Btu/h-W)*	
		Product Class 8A: Without Reverse Cycle, Without Louvered Sides, 8,000-10,999 Btu/h	**Product Class 8B: Without Reverse Cycle, Without Louvered Sides, 11,000 - 13,999 Btu/h**
Baseline	DOE Standard	8.5	8.5
1	Energy Star	9.4	9.4
2	Gap Fill 1	9.7	9.6
3	Gap Fill 2	10.1	9.8
4	Max-Tech	10.4	10.1

5.4.2.2 Standby Mode and Off Mode

For **clothes dryers** DOE observed through testing and teardowns that several different features could be associated with successively lower standby power levels (SLs). Therefore, DOE was able to define several standby power levels for analysis. Only standby power is addressed because no power consumption was observed in the off mode for test units capable of such a mode. At the baseline standby power level of 2.0 W, the clothes dryer is estimated to be equipped with a full complement of cycle settings, a linear regulated control board power supply, and a display which powers down after a period of user inactivity. The automatic deactivation of electronic displays was observed in all tested units so equipped and was therefore considered a baseline feature.

SL 1 is associated with changing from a conventional power supply to a switch-mode power supply. For SL 2, a transformerless power supply enables a microcontroller to remain on at all times while disabling the main power supply whenever the clothes dryer is "asleep". The control logic monitors the clothes dryer for key-presses, door openings, etc., and when user activity is detected, the logic activates the main power supply. These standby power levels, shown in Table 5.4.20, are believed to be the same for all clothes dryer product classes.

Table 5.4.20 Clothes Dryer Standby Power Levels

Level	Standby Power Source	Power Input *(W)*
Baseline	DOE Test Data and Analysis	2.0
1	DOE Test Data	1.5
2	DOE Test Data (Max-Tech)	0.08

For **room air conditioners**, DOE selected a single incremental standby power level for standby mode, based on the data presented in Table 5.4.6 above. The standby mode power input at SL 1 is 0.7 W, which was observed in one of the room air conditioners in the test sample and nearly achieved by a second unit.

Baseline room air conditioners with electronic controllers featured a linear regulated power supply and an infrared detector for the remote control. All sampled units with electronic controllers featured a remote control. SL 1 was met by one of the room air conditioners in the test sample and was nearly achieved by a second unit. DOE research suggests that SL1 can be achieved through the substitution of a switch-mode power supply, since both units that met or nearly met SL1 used such power supplies. All other electronic-controlled units used conventional linear regulated power supplies. The selected standby power levels are summarized in Table 5.4.21 below.

Table 5.4.21 Room Air Conditioner Standby Power Levels

Level	**Standby Power Source**	**Power Input** *(W)*
Baseline	DOE Test Data	1.4
1	DOE Test Data	0.7

5.4.2.3 Integrated Efficiency

As part of the preliminary analysis for **clothes dryers**, incremental IEF efficiency levels were determined by assuming that a clothes dryer with baseline energy efficiency (EF) performance would incorporate baseline standby power consumption (*i.e.*, 2.0 W). DOE recognizes that many clothes dryers that just meet the current Federal energy conservation standards for EF utilize electromechanical controls, which consume no standby power. There are, however, a significant number of models rated at baseline energy efficiency performance that incorporate electronic controls. Thus, DOE assumed that the baseline IEF level for a minimally-compliant unit should include the 2.0 W of standby power. At higher IEF levels, DOE estimated for the preliminary analysis that standby power would remain at 2.0 W for those levels that do not strictly require electronic controls to achieve. For those higher levels that do require electronic controls, DOE added in the design options for standby power improvements in order of cost effectiveness. This resulted in the incremental IEF efficiency levels proposed for the preliminary analysis shown in Table 5.4.22 through Table 5.4.24.

Table 5.4.22 Preliminary Analysis Clothes Dryer Integrated Efficiency Levels (IEF) – Vented Product Classes

Level	**Efficiency Level Description**	**Integrated Efficiency Level (IEF)** *(lb/kWh)*			
		Electric Standard	**Electric Compact (120V)**	**Electric Compact (240V)**	**Gas**
Baseline	DOE Standard + 2.0 W Standby	2.96	3.00	2.79	2.63
1	Gap Fill + 2.0 W Standby	3.04	3.08	2.86	2.71
2	Gap Fill + 2.0 W Standby	3.10	3.15	2.96	2.80
3	Gap Fill/Maximum Available + 2.0 W Standby	3.33	3.37	3.06	2.97
4	Maximum Available + 1.5 W Standby	3.35	3.41	3.10	2.98
5	Maximum Available + 0.08 W Standby	3.40	3.53	3.19	3.02
6	Heat Pump (Max Tech) + 0.08 W Standby	4.52	4.69	4.34	

Table 5.4.23 Preliminary Analysis Clothes Dryer Integrated Efficiency Levels (IEF) – Ventless Electric Compact (240V)

Level	Efficiency Level Description	Integrated Efficiency Level (IEF) *(lb/kWh)*
		Electric Compact (240 V)
Baseline	Baseline + 2.0 W Standby	2.29
1	Baseline + 1.5 W Standby	2.31
2	Baseline + 0.08 W Standby	2.37
3	Gap Fill + 0.08 W Standby	2.39
4	Gap Fill + 0.08 W Standby	2.59
5	Heat Pump (Max-Tech) + 0.08 W Standby	3.54

Table 5.4.24 Preliminary Analysis Clothes Dryer Integrated Efficiency Levels (IEF) – Ventless Electric Combination Washer/Dryers

Level	Efficiency Level Description	Integrated Efficiency Level (IEF) *(lb/kWh)*
		Electric Combination Washer/Dryer
Baseline	Baseline + 2.0 W Standby	1.90
1	Gap Fill + 2.0 W Standby	2.15
2	Gap Fill + 2.0 W Standby	2.34
3	Gap Fill + 1.5 W Standby	2.36
4	Gap Fill + 0.08 W Standby	2.42
5	Heat Pump (Max-Tech) + 0.08 W Standby	3.31

Based on the revised active mode efficiency levels for the final rule analyses presented above in section 5.4.2.1 and the standby power levels presented in section 5.4.2.2, DOE revised the incremental CEF efficiency levels. As discussed above, for the preliminary analysis, DOE only incorporated incremental standby power levels into IEF efficiency levels above which electronic controls would be required as part of the active mode design option changes. At that point, DOE then incorporated the incremental standby power levels where it determined them to be most cost effective. However, DOE believes that the low cost of the standby power design options should result in these technologies being layered in at the efficiency levels where these design options are most cost-effective (regardless of whether electronic controls are required for the active mode design options). As a result, for the final rule, DOE revised the order of the design options and efficiency levels presented in the preliminary analysis such that the standby power levels are applied immediately above the baseline level. DOE also noted that for the integrated efficiency levels where electronic controls are not required for the design changes, the standby power level changes would impact only those clothes dryers that consume standby power (*i.e.*, those products with electronic controls). DOE analyzed baseline efficiency products available on the U.S. market, and weighted the efficiency improvement and incremental manufacturing cost associated with standby power based on the percentage of baseline efficiency products that have electronic controls. DOE's review of currently available models with baseline efficiency showed that roughly 74 percent of models have electronic controls. For the integrated efficiency levels for which electronic controls are required as part of the active mode design changes, DOE assumed that the standby power levels and incremental manufacturing costs (presented below in section 5.6.1.4) affected 100 percent of clothes dryer models. The incremental CEF efficiency levels are shown in Table 5.4.25 through Table 5.4.27.

Table 5.4.25 Clothes Dryer Integrated Efficiency Levels (CEF) – Vented Product Classes

Level	Efficiency Level Description	Integrated Efficiency Level (CEF) *(lb/kWh)*			
		Electric Standard	Electric Compact (120V)	Electric Compact (240V)	Gas
Baseline	DOE Standard + 2.0 W Standby	3.55	3.43	3.12	3.14
1	DOE Standard + 1.5 W Standby	3.56	3.48	3.16	3.16
2	DOE Standard + 0.08 W Standby	3.61	3.61	3.27	3.20
3	Gap Fill + 0.08 W Standby	3.73	3.72	3.36	3.30
4	Gap Fill + 0.08 W Standby	3.81	3.80	3.48	3.41
5	Gap Fill/Maximum Available + 0.08 W Standby	4.08	4.08	3.60	3.61
6	Heat Pump (Max-Tech) + 0.08 W Standby	5.42	5.41	4.89	

Table 5.4.26 Clothes Dryer Integrated Efficiency Levels (CEF) – Ventless Electric Compact (240V)

Level	Efficiency Level Description	Integrated Efficiency Level (CEF) *(lb/kWh)*
		Electric Compact (240 V)
Baseline	Baseline + 2.0 W Standby	2.55
1	Baseline + 1.5 W Standby	2.59
2	Baseline + 0.08 W Standby	2.69
3	Gap Fill + 0.08 W Standby	2.71
4	Gap Fill + 0.08 W Standby	2.80
5	Heat Pump (Max-Tech) + 0.08 W Standby	4.03

Table 5.4.27 Clothes Dryer Integrated Efficiency Levels (CEF) – Ventless Electric Combination Washer/Dryers

Level	Efficiency Level Description	Integrated Efficiency Level (CEF) *(lb/kWh)*
		Electric Combination Washer/Dryer
Baseline	Baseline + 2.0 W Standby	2.08
1	Gap Fill + 2.0 W Standby	2.35
2	Gap Fill + 1.5 W Standby	2.38
3	Gap Fill + 0.08 W Standby	2.46
4	Gap Fill + 0.08 W Standby	2.56
5	Heat Pump (Max-Tech) + 0.08 W Standby	3.69

During the preliminary analysis, incremental IEER efficiency levels for **room air conditioners** were established at values rounded to the nearest tenth, except for the baseline levels described in section 5.4.1.3. The levels were chosen to correspond to the EER efficiency levels in the preliminary analysis discussed in section 5.4.2.1 as closely as was feasible. The selected levels are summarized in Table 5.4.28 and Table 5.4.29 below.

Table 5.4.28 Preliminary Analysis Room Air Conditioner Integrated Efficiency Levels (IEER)--Product Classes 1 and 3

Level	IEER *(Btu/h-W)*	
	1: Without Reverse Cycle, With Louvered Sides, < 6,000 Btu/h	3:Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h
Baseline	9.52	9.71
1	10.1	10.3
2	10.6	10.8
3	11.1	11.3
4	11.6	11.5
5	12.0	

Table 5.4.29 Preliminary Analysis Room Air Conditioner Integrated Efficiency Levels (IEER)--Product Classes 5 and 8

Level	IEER *(Btu/h-W)*	
	5:Without Reverse Cycle, With Louvered Sides, ≥ 20,000 Btu/h	8:Without Reverse Cycle, Without Louvered Sides, 8,000 – 13,999 Btu/h
Baseline	8.47	8.43
1	9.0	8.9
2	9.4	9.3
3	9.8	9.8
4	10.0	-

As detailed in the section above, DOE modified its active mode efficiency levels for the final rule analysis, and renamed the integrated metric. Based on these changes, incremental CEER efficiency levels for **room air conditioners** were established at values rounded to the nearest tenth, except for the baseline levels described in section 5.4.1.3. The levels were chosen to correspond to the extent feasible with the EER efficiency levels selected for the active mode efficiency , which are discussed in section 5.4.2.1. The selected integrated efficiency levels are summarized in Table 5.4.30 to Table 5.4.32 below.

Table 5.4.30 Room Air Conditioner Integrated Efficiency Levels (CEER)--Product Classes 1 and 3

Level	CEER *(Btu/h-W)*	
	1: Without Reverse Cycle, With Louvered Sides, < 6,000 Btu/h	3:Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h
Baseline	9.52	9.71
1	10.1	10.2
2	10.6	10.7
3	11.1	10.9
4	11.4	11.5
5	11.7	12.0

Table 5.4.31 Room Air Conditioner Integrated Efficiency Levels (CEER)--Product Classes 5A and 5B

Level	CEER *(Btu/h-W)*	
	5A:Without Reverse Cycle, With Louvered Sides, 20,000-27,999 Btu/h	**5B:Without Reverse Cycle, With Louvered Sides, ≥ 28,000 Btu/h**
Baseline	8.47	8.48
1	9.0	8.9
2	9.4	9.4
3	9.8	9.8
4	10.15	-

Table 5.4.32 Room Air Conditioner Integrated Efficiency Levels (CEER)--Product Classes 8A and 8B

Level	CEER *(Btu/h-W)*	
	8A:Without Reverse Cycle, Without Louvered Sides, 8,000 – 10,999 Btu/h	**8B:Without Reverse Cycle, Without Louvered Sides, 11,000 – 13,999 Btu/h**
Baseline	8.41	8.44
1	9.3	9.3
2	9.6	9.5
3	10.0	9.8
4	10.4	10.0

5.5 METHODOLOGY OVERVIEW

DOE typically uses data submitted by AHAM as the primary source of cost information for the engineering analysis. AHAM provided DOE with aggregated incremental manufacturing cost data from its member companies for several product classes of vented clothes dryers. However, AHAM did not receive enough responses from members to allow aggregation and reporting of data for the remaining clothes dryer product classes and all room air conditioner product classes.

For **clothes dryers**, DOE conducted an independent review of the AHAM data using several methods and data sources. To gain a better understanding of the data submitted by member companies and to be able to relate the costs of improving efficiency to discrete (or system) technologies, DOE reviewed the TSD from the previous rulemaking and conducted interviews with clothes dryer manufacturers. DOE also performed detailed product teardowns and cost modeling on several clothes dryer models spanning a range of efficiencies to generate cost-efficiency curves. These cost-efficiency relationships were compared to the AHAM data for validation. Finally, DOE conducted standby power testing, as well as detailed energy performance testing at an independent laboratory to gain insights into energy performance in active, standby, and off modes, and disaggregated energy use of components and subsystems.

For **room air conditioners**, in the absence of industry-supplied data, DOE conducted energy modeling analysis of the products obtained for reverse engineering analysis, product designs for R-410A refrigerant based on the reverse engineering products, and product designs using R-410A that incorporate energy-saving design options. The manufacturing cost model developed in conjunction with the reverse-engineering work was used to determine the incremental costs associated with the high-efficiency product designs evaluated in the energy modeling in order to allow development of cost-efficiency relationships for products using R-410A refrigerant. DOE supplemented these analysis with a review of the TSD from the previous rulemaking, product testing at an independent laboratory, and manufacturer interviews. Table 5.5.1 below shows which methods DOE used for each product.

Table 5.5.1 Engineering Analysis Methods

Method	Product	
	Clothes Dryers	**Room Air Conditioners**
AHAM Data	√	
Review of Previous TSD	√	√
Product Teardown and Manufacturing Cost Modeling	√	√
Product Testing	√	√
Manufacturer Interviews	√	√
Energy Modeling		√

5.5.1 AHAM Data Request

In support of this rulemaking effort, DOE requested incremental cost data from AHAM for both of the product categories. (See appendix 5A of this TSD for the data request sheets.) The data represent the average incremental production cost to improve a baseline unit to a specified efficiency level. This methodology constitutes an efficiency-level approach to the engineering analysis because DOE examined aggregated incremental increases in manufacturer selling price at specified levels of energy efficiency. In addition, DOE requested shipments, shipment-weighted average efficiency, and market share efficiency data. As noted in section 5.4.2.3, AHAM did not receive enough responses from members in order to allow aggregation and reporting of incremental cost data for room air conditioners. Tables of aggregated data for clothes dryers provided to DOE by AHAM are contained in appendix 5B of this TSD.

5.5.2 Manufacturer Interviews

AHAM provided to DOE shipment-weighted average manufacturer costs and capital expenditures. To better understand the manufacturer costs, DOE supplemented these data with information obtained through follow-up manufacturer interviews. These confidential interviews provided a deeper understanding of the various combinations of technologies used to increase product efficiency, and their associated manufacturing costs. Sample questions asked during interviews are contained in appendix 5C of this TSD.

During the interviews, DOE also gathered information about the capital expenditures required to increase the efficiency of the baseline units to various efficiency levels (*i.e.*, conversion capital expenditures by efficiency or energy-use level). The interviews provided information about the size and the nature of the capital investments. DOE also requested information about the depreciation method used to expense the conversion capital.

5.5.3 Product Teardowns

Other than obtaining detailed manufacturing costs directly from a manufacturer, the most accurate method for determining the production cost of a product is to disassemble the unit piece-by-piece and estimate the material and labor cost of each component using a process commonly called a physical teardown. A supplementary method, called a catalog teardown, uses published manufacturer catalogs and supplementary component data to estimate the major physical differences between a product that has been physically disassembled and another similar product. DOE performed physical teardown analysis on both clothes dryers and room air conditioners. The teardown methodology is explained in section 5.5.3.1 and section 5.5.3.2.

Selection of Units

During the process of selecting units for teardown, DOE considered 3 main questions:

- What efficiency levels should be captured in the teardown analysis?
- Are there units on the market that capture all potential efficiency levels and design options?
- Which of the available units are most representative?

In responding to the preceding questions, DOE generally adopts the following criteria for selecting units for teardown analysis:

- The selected products should span the full range of efficiency levels for each product class under consideration;
- Within each product class, if possible, the selected products should come from the same manufacturer and be within the same product series;
- The selected products should primarily come from manufacturers with large market share in that product class, although the highest efficiency products were chosen irrespective of manufacturer; and
- The selected products should have non-efficiency-related features that are the same as, or similar to, features of other products in the same class and at the same efficiency level.

Additional criteria for selecting the teardown units specific to each product category are described in section 5.6.1.3 for clothes dryers and section 5.6.2.3 for room air conditioners.

5.5.3.1 Generation of Bill of Materials

The end result of each teardown is a structured bill of materials (BOM). Structured BOMs describe each equipment part and its relationship to the other parts, in the estimated order of assembly. The BOMs describe each fabrication and assembly operation in detail, including the type of equipment needed (*e.g.*, stamping presses, injection molding machines, spot-welders, etc.) and the process cycle times. The result is a thorough and explicit model of the production process.

The BOMs incorporate all materials, components, and fasteners, classified as either raw materials or purchased parts and assemblies. The classification into raw materials or purchased parts is based on DOE's previous industry experience, recent information in trade publications, and discussions with high- and low-volume original equipment manufacturers (OEMs).

For purchased parts, the purchase price is an estimate based on volume-variable price quotations and detailed discussions with suppliers. For parts fabricated in-house, the prices of "raw" metals (*e.g.*, tube, sheet metal) are estimated on the basis of 5-year averages. Other "raw" materials such as plastic resins, insulation materials, etc. are estimated on a current-market basis.

The cost of raw materials was determined using prices for copper, steel and aluminum from the American Metals Market.[4] The prices for rifled and unrifled copper tubing were obtained directly from a tubing manufacturer.

The price of steel drastically increased in 2005, and the price of copper has increased steadily since 2004. Because DOE is using a 5-year average in material prices from 2005-2009, these price increases are normalized, which better represents long-term material prices.

In order to assure that raw material prices DOE used in manufacturing cost estimates are representative of actual costs paid by OEMs, DOE sent a separate material cost questionnaire to the manufacturers that participated in the technical interviews.

5.5.3.2 Cost Structure of the Spreadsheet Models

The manufacturing cost assessment methodology used is a detailed, component-focused technique for rigorously calculating the manufacturing cost of a product (direct materials, direct labor and some overhead costs). Figure 5.5.1 shows the three major steps in generating the manufacturing cost.

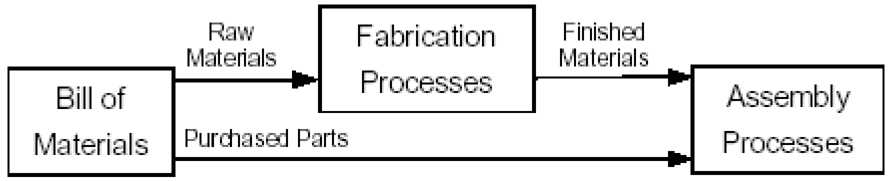

Figure 5.5.1 Manufacturing Cost Assessment Stages

The first step in the manufacturing cost assessment was the creation of a complete and structured BOM from the disassembly of the units selected for teardown. The units were dismantled, and each part was characterized according to weight, manufacturing processes used, dimensions, material, and quantity. The BOM incorporates all materials, components, and fasteners with estimates of raw material costs and purchased part costs. Assumptions on the sourcing of parts and in-house fabrication were based on industry experience, information in trade publications, and discussions with manufacturers. Interviews and plant visits were conducted with manufacturers to ensure accuracy on methodology and pricing.

Following the development of a detailed BOM, the major manufacturing processes were identified and developed for the spreadsheet model. These processes are listed in Table 5.5.2.

Table 5.5.2 Major Manufacturing Processes

Fabrication	**Finishing**	**Assembly/Joining**	**Quality Control**
Fixturing	Washing	Adhesive Bonding	Inspecting & Testing
Stamping/Pressing	Powder Coating	Spot Welding	
Brake Forming	De-burring	Seam Welding	
Cutting and Shearing	Polishing	Packaging	
Insulating	Refrigerant Charging		
Turret Punch			
Tube Forming			
Enameling			

Fabrication process cycle times were estimated and entered into the BOM. In the final step of the cost assessment, assembly times and associated direct labor costs were estimated. Once the cost estimate for each teardown unit was finalized, a detailed summary was prepared for relevant components, subassemblies and processes. The BOM thus details all aspects of unit costs.

Design options used in units subject to teardown are noted in the summary sheet of each cost model and are cost-estimated individually. Thus, various implementations of design options can be accommodated, ranging from assemblies that are entirely purchased to units that are made entirely from raw materials. Hybrid assemblies, consisting of purchased parts and parts made on site are thus also accommodated.

5.5.3.3 Cost Model and Definitions

Once DOE disassembled selected units, gathered information from manufacturer catalogs on additional products, and identified technologies, DOE created an appropriate manufacturing cost model that could translate physical information into manufacturing production costs. The cost model is based on production activities and divides factory costs into the following categories:

- Materials: Purchased parts (*i.e.*, gas valves, blower motors, etc.), raw materials, (*i.e.*, cold rolled steel, copper tube, etc.), and indirect materials that are used for processing and fabrication.
- Labor: Fabrication, assembly, indirect, and supervisor labor. Fabrication and assembly labor cost are burdened with benefits and supervisory costs.
- Overhead: Equipment, tooling, and building depreciation, as well as utilities, equipment and tooling maintenance, insurance, and property taxes.

Cost Definitions

Because there are many different accounting systems and methods to monitor costs, DOE defined the above terms as follows:

- Direct material: Purchased parts (out-sourced) plus manufactured parts (made in-house from raw materials).
- Indirect material: Material used during manufacturing (*e.g.*, welding rods, adhesives).
- Fabrication labor: Labor associated with in-house piece manufacturing.
- Assembly labor: Labor associated with final assembly.
- Indirect labor: Labor costs that scaled with fabrication and assembly labor. This included the cost of technicians, manufacturing engineering support, stocking, etc. that were assigned on a span basis.
- Equipment and plant depreciation: Money allocated to pay for initial equipment installation and replacement as the production equipment is amortized.
- Tooling depreciation: Cost for initial tooling (including non-recurring engineering and debugging of the tools) and tooling replacement as it wears out or is rendered obsolete.
- Building depreciation: Money allocated to pay for the building space and the conveyors that feed and/or make up the assembly line.
- Utilities: Electricity, gas, telephones, etc.
- Maintenance: Annual money spent on maintaining tooling and equipment.
- Insurance: Appropriated as a function of unit cost.
- Property Tax: Appropriated as a function of unit cost.

5.5.3.4 Cost Model Assumptions

As discussed in the previous section, assumptions about manufacturer practices and cost structure played an important role in estimating the final product cost. In converting physical information about the product into cost information, DOE reconstructed manufacturing processes for each component using internal expertise and knowledge of the methods used by the industry. DOE used assumptions regarding the manufacturing process parameters (*e.g.*, equipment use, labor rates, tooling depreciation, and cost of purchased raw materials) to determine the value of each component. DOE then summed the values of the components into assembly costs and, finally, the total product cost. The product cost included the material, labor, and overhead costs associated with the manufacturing facility. The material costs included both direct and indirect materials. The labor costs included fabrication, assembly, indirect, direct, and supervisor labor rates, including the associated overhead. The labor costs were determined by the type of product (clothes dryer and room air conditioner) manufactured at the factory. Overhead costs included equipment depreciation, tooling depreciation, building depreciation, utilities, equipment, tooling maintenance, insurance, property, and taxes.

5.5.4 Review of Previous Technical Support Documents and Models

DOE reviewed previous rulemaking TSDs to assess their applicability to the current standard setting process for residential clothes dryers and room air conditioners. These previous rulemaking TSDs served as a source for design options and energy consumption analysis, in addition to other sources. For room air conditioners, the energy model used in the previous rulemaking was updated for use in the current one.

5.5.5 Product Testing

DOE conducted product testing on clothes dryers and room air conditioners according to the relevant DOE test procedures to develop a better understanding of the potential efficiency improvements of design options and to develop disaggregated efficiency data. In addition, DOE performed standby and off mode testing to help evaluate possible standby and off modes, energy use in each mode, and strategies manufacturers may take to reduce standby power.

5.6 ANALYSIS AND RESULTS

5.6.1 Clothes Dryers

The clothes dryer engineering analysis was performed by considering cost and efficiency information from multiple sources. AHAM provided incremental manufacturing costs for all but the highest efficiency levels of interest to DOE for vented electric standard and gas clothes dryers. No data were provided for vented electric compact (120 V) and (240 V) or ventless electric compact (240 V) and electric combination washer/dryer product classes. DOE supplemented these data points by conducting its own engineering analysis, comprised of performance testing at an independent laboratory, standby power testing, and manufacturing cost estimates from detailed teardowns of currently-available clothes dryers. Manufacturer interviews were also conducted to obtain greater insight into the design strategies to improve efficiency and the associated costs. DOE conducted preliminary manufacturer interviews after the framework document. DOE also conducted additional manufacturer interviews for the final rule analysis.

5.6.1.1 AHAM Data

AHAM provided to DOE shipment data from its member companies for clothes dryers. Table 5.6.1 shows market share by EF[e] ranges for electric standard and gas clothes dryer shipments in the years 2005 and 2006. AHAM noted that, in order to maintain confidentiality, market share for electric standard dryers between EF of 3.20 and 3.29 were incorporated into the EF range between 3.10 and 3.19. Similarly, market share for gas clothes dryers with an EF > 2.94 was incorporated into the EF > 2.85 efficiency bin. AHAM stated it was not able to obtain sufficient data for vented electric compact (120 V) and (240 V). In addition, market share data for ventless dryers was unavailable since EF is not currently measured.

Table 5.6.1 AHAM Clothes Dryer Market Share Data Submittal

Vented Electric Standard			**Vented Gas**		
EF Range *(lb/kWh)*	**Market Share for 2005** *(%)*	**Market Share for 2006** *(%)*	**EF Range** *(lb/kWh)*	**Market Share for 2005** *(%)*	**Market Share for 2006** *(%)*
3.01-3.09 (Baseline = 3.01)	26	33	2.67-2.74 (Baseline = 2.67)	25	28
3.10-3.29	74	67	2.75-2.84	42	44
3.20-3.29			>2.85	32	27
>3.29					

On a shipment-weighted basis, the average efficiencies of electric standard and gas clothes dryers sold in the United States have been stable for the past few years, according to the AHAM-submitted data shown in Table 5.6.2.

[e]All clothes dryer EF data provided by AHAM is based on EF values as measured by the previous DOE clothes dryer test procedure.

Table 5.6.2 AHAM Clothes Dryer Shipments and Shipment-Weighted Efficiency Data Submittal

Year	Shipments, Domestic + Imports (*Thousands of Units*)						Shipment-Weighted Average Efficiency(EF, *cycles/kWh*)			
	Vented				Ventless		Vented			
	Electric				Electric		Electric			
	All Electric	Standard	All Compact	Gas	Compact 240 V	Combo	Standard	Compact 120 V	Compact 240 V	Gas
1993	3,674			1,156						
1994	3,838			1,239						
1995	3,823			1,169						
1996	3,947			1,193						
1997	4,115			1,195						
1998	4,482			1,307						
1999	4,865			1,444						
2000	5,095			1,480						
2001	5,117			1,384						
2002	5,402			1,490						
2003	5,718	5,622	96	1,616						
2004	6,262	6,159	103	1,660						
2005	6,408	6,330	78	1,707			3.10			2.70
2006	6,360	6,246	114	1,614			3.10			2.70

AHAM provided incremental manufacturing cost data for the first three efficiency levels for vented electric standard and gas clothes dryers presented in the framework document, as shown in Table 5.6.3. At the time DOE requested data from AHAM, the efficiency levels of interest were specified as those in the framework document, which were subsequently updated during the preliminary analysis based on more recent market information, comments from interested parties, and manufacturer interviews. Therefore, the AHAM cost data are presented at the original values of EF to which the aggregated data correspond, while DOE's cost estimates are presented at the updated levels.

Table 5.6.3 AHAM Clothes Dryer Incremental Cost Data Submittal

		Vented Electric Standard			Vented Gas		
Efficiency Level		**1**	**2**	**3**	**1**	**2**	**3**
EF Level, [Original] *(lb/kWh)*		**3.10**	**3.16**	**3.39**	**2.75**	**2.77**	**3.02**
Average Shipment-Weighted Incremental Cost *($)* for each EF level	Material	9	42	140	20	60	81
	Labor	2	11	45	2	6	32
	Overhead	2	4	12	2	4	12
Conversion Capital Expenditure Assumptions, *(Million $)*, Total for all Manufacturers	Building	0.25	9.02	50.18	0.46	29.83	
	Tooling and Equipment	5.25	37.68	118.93	2.62	37.24	16.15
Avg. One-Time Product Conversion Expenses, *(Million $)*, Total for all Manufacturers	R&D	3.62	15.87	58.97	2.99	15.46	12.91
	Marketing						

Notes
1. While all members use straight-line depreciation, AHAM was not able to obtain a consistent response on the years used in the calculation.
2. Shaded cells indicate that AHAM did not receive enough input to aggregate incremental cost data.

Figure 5.6.1 plots the average incremental cost as a function of EF (based on the previous DOE clothes dryer test procedure) for the AHAM clothes dryer data. The lowest point on the graph indicates the baseline level and therefore has a cost increment of $0. Note that the gas curve exhibits a steep increase between EL 2 and EL 3. Based on manufacturer interviews, DOE believes that AHAM members suggested fairly significant design changes in order to reach EL 3, even though the original EF values for EL 2 and EL 3 were quite close.

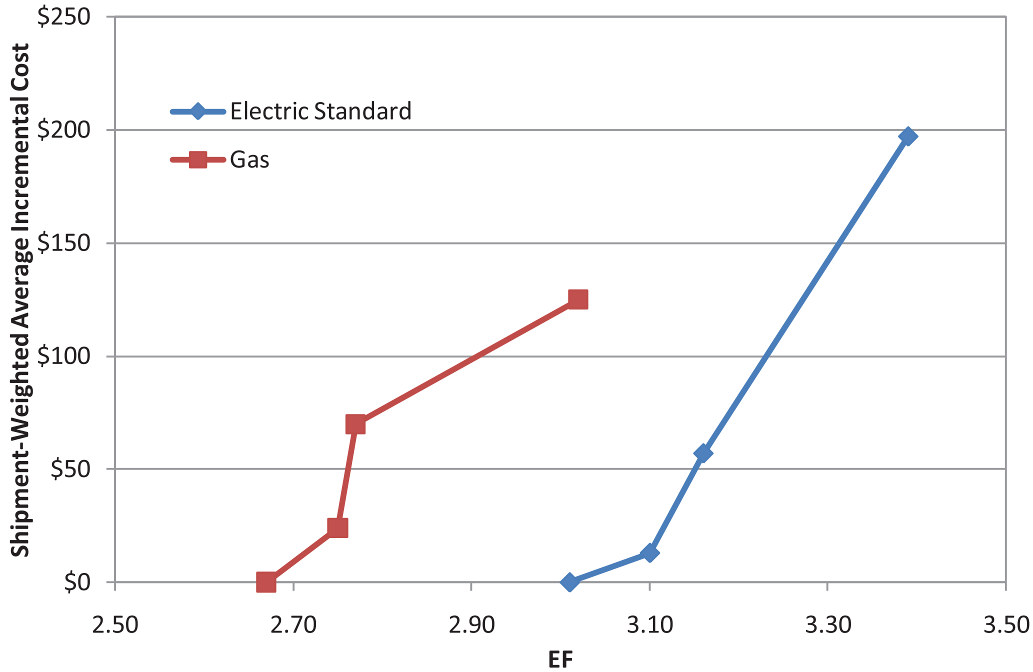

Figure 5.6.1 AHAM Clothes Dryer Cost-Efficiency Curves

In addition to the cost and efficiency data, AHAM provided information to help DOE evaluate a potential change to the clothes dryer test procedure to reflect more current product characteristics. The previous DOE clothes dryer test procedure assumed an initial RMC of the test cloth load of 70.0 ± 3.5 percent. However, DOE noted that this RMC value is likely no longer representative of typical residential clothes washers that use higher spin speeds to remove moisture at the end of the wash cycle. Therefore, DOE requested data from AHAM to help evaluate the effect of a lower initial RMC on measured EF, as well as to characterize the trends in shipment-weighted clothes washer RMC. Figure 5.6.2 illustrates the data AHAM provided for the change in EF that is measured when RMC is reduced from nominally 70 percent to nominally 56 percent. It can be seen that, in AHAM's test sample of 11 baseline clothes dryers, EF decreased by an average of 4 percent when RMC was reduced as described and the existing test procedure was used to calculate EF. Average EF decreased from 3.09 to 2.97 lb/kWh. The test procedure, however, contains a provision in the calculation of per-cycle energy consumption that is intended to normalize EF by the reduction in RMC over the course of the drying cycle. There is a scaling factor applied of 66, which is supposed to represent the nominal change in percent from the starting RMC to the ending one, which is derived from the assumption that the nominal starting RMC is 70 percent and the nominal ending RMC is 4 percent. If the calculation in the test procedure is adjusted to maintain what DOE believes is the intent for normalization of the results, the scaling factor should be changed to 52 to reflect a starting point of 56 percent RMC rather than 70 percent. If that adjustment is made to the AHAM data, EF increases by an average of 22 percent by changing from 70 to 56 percent initial RMC.

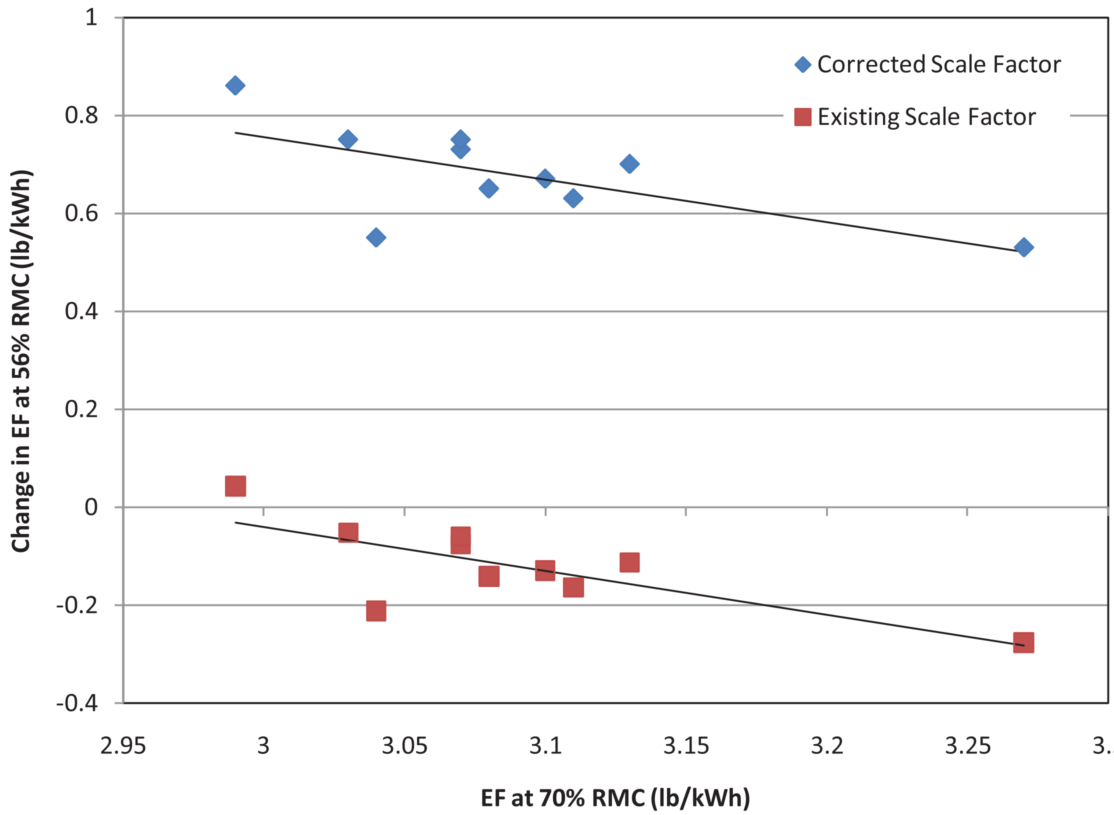

Figure 5.6.2 AHAM Data Submittal for Impact of Initial RMC on Clothes Dryer EF

AHAM also provided data for shipments of residential clothes washers for which RMC was reported, along with shipment-weighted RMC. (See Table 5.6.4) These data sets, each of which were disaggregated for front-loading and top-loading clothes washers as well as reported as overall values for all clothes washers, provide insight into what initial clothes dryer RMC would be most representative of current clothes washers. RMC has been decreasing consistently, and the data suggest that the initial RMC in the clothes dryer test procedure of nominally 70 percent is higher than the current shipment-weighted clothes washer average.

Table 5.6.4 AHAM Shipment-Weighted Clothes Washer RMC Data Submittal

Year	Clothes Washer Shipments for Which RMC was Reported			Shipment-Weighted RMC* *(%)*		
	Front-Loading	**Top-Loading**	**Total**	**Front-Loading**	**Top-Loading**	**Overall**
2000	232,714	686,440	919,154	43.6	57.4	53.9
2001	235,989	473,629	709,618	41.3	57.7	52.2
2002	280,667	529,265	809,932	41.5	58.1	52.3
2003	351,411	1,676,877	2,028,288	43.1	54.5	52.5
2004	1,179,813	5,270,285	6,450,098	42.2	52.8	50.9
2005	1,563,108	5,394,511	6,957,619	40.8	52.7	50.1
2006	1,851,218	15,528,279	17,379,497	39.3	51.8	50.5
2007	1,973,825	15,271,142	17,244,967	38.3	51.8	50.2
2008	2,043,024	4,492,059	6,535,083	38.1	51.0	47.0

* Shipment-weighted average clothes washer RMC data measured using the DOE clothes washer test procedure which applies an RMC correction factor

5.6.1.2 Product Testing

For the preliminary analysis, DOE conducted a market survey of clothes dryer models and their associated features and selected five electric standard, one electric compact (240 V), and four gas vented clothes dryers from multiple manufacturers. For ventless clothes dryers, DOE selected one electric compact (240 V) and one electric combination washer/dryer model. These selections were based on the proposed efficiency levels and the range of product efficiencies available on the market. Because there is no EnergyGuide label required for residential clothes dryers, DOE based the selection of units for teardown on the efficiency data available in the CEC product database. DOE was unable to test an electric compact (120 V) clothes dryer since no such model was found to be on the market in the United States. Table 5.6.5 and Table 5.6.6 list features of the tested units.

Table 5.6.5 Vented Electric Standard Clothes Dryer Test Unit Features

Feature	Clothes Dryer Test Unit Designation				
	Vented Electric Standard				
	#1	**#2**	**#3**	**#4**	**#5**
Rated EF *(cycle/kWh)*	3.06	3.10	3.15	3.20	3.4
Rated Drum Capacity (ft^3)	7	7	7	5.9	6.1
Controls	Electromechanical	Electromechanical with Moisture Sensor PCB	Electronic	Electromechanical	Electronic
Drum Type	Full Cylinder	Open Cylinder	Open Cylinder	Open Cylinder	Full Cylinder
Number of Motors	2	1	1	1	1
Motor Type(s)	PSC + Induction	Induction	Induction	Induction	PSC
Air Flow Direction	Back to Front	Back to Back	Back to Back	Back to Back	Back to Front
Dedicated Hot Air Duct?	No	Yes	Yes	Yes	Yes
Inlet Air Preheat?	No	No	No	No	No
Heating Modulation?	No	No	No	No	No
Automatic Cycle Termination?	Yes	Yes	Yes	Yes	Yes
Sensor Type(s)	Temp	Temp + Moisture	Temp + Moisture	Temp + Moisture	Temp + Moisture

Table 5.6.6 Vented Electric Compact (240 V), Gas, and Ventless Clothes Dryer Test Unit Features

Feature	Clothes Dryer Test Unit Designation						
	Vented Electric Compact (120 V)	Vented Gas				Ventless Electric Compact (240 V)	Ventless Electric Combo
	#6	#7	#8	#9	#10	#11	#12
Rated EF *(cycle/kWh)*	2.98	2.67	2.76	2.80	3.00		
Rated Drum Capacity (ft^3)	3.4	5.2	6.7	7	7,3	2.5	2.5
Controls	Electromechanical	Electromechanical	Electronic	Electronic	Electronic	Electronic	Electronic
Drum Type	Open Cylinder	Full Cylinder	Open Cylinder	Open Cylinder	Open Cylinder	Full Cylinder	Full Cylinder
Number of Motors	1	1	1	1	1	1	2
Motor Type(s)	Induction	Induction	Induction	Induction	Induction	PSC	PSC + Induction
Air Flow Direction	Back to Back	Back to Front	Back to Front	Back to Front	Back to Front	Back to Front	Front to Back
Dedicated Hot Air Duct?	Yes	No	Yes	Yes	Yes	Yes	Yes
Inlet Air Preheat?	No	No	No	No	No	No	No
Heating Modulation?	No	No	No	No	No	No	No
Automatic Cycle Termination?	Yes	Yes	Yes	Yes	Yes	Yes	No
Sensor Type(s)	Temp + Moisture	Temp	Temp + Moisture	Temp + Moisture	Temp + Moisture	Temp	

Active Mode Testing

Clothes dryer testing was performed for the preliminary analysis on the twelve units in the test sample. The test results included not only the measurements required to evaluate the performance according to the previous DOE test procedure, but sub-metered component energy consumption data as well, which enabled DOE to quantify patterns of energy consumption during various stages of the cycle and identify energy efficiency and other drying performance strategies. Each clothes dryer was tested at an independent laboratory according to the previous DOE test procedure (10 CFR 430 subpart B, appendix D). For the ventless units, the test was run without the use of the exhaust simulator.

The test procedure consisted of running a load of preconditioned test cloth in the clothes dryer at the maximum temperature setting and, if equipped with a timer, at the maximum time setting. For standard-size dryers (*i.e.*, with a drum capacity of 4.4 cubic feet (ft^3) or greater), the nominal test load weight is 7.00 lb. For compact-size dryers (*i.e.*, with a drum capacity less than 4.4 ft^3), the nominal test load weight is 3.00 lb. Prior to loading the drum, the cloth is dampened and spun to obtain an RMC of 66.5–73.5 percent. Once the cycle is started, the test load is dried until the RMC is 2.5–5.0 percent, resetting the timer or automatic dry control if necessary.

During this test cycle, the total kWh of electric energy consumed by the clothes dryer is measured, in addition to the "bone dry"[f] weight of the test load and the starting and ending RMC. For gas clothes dryers, the measurements also include the cubic feet of gas used during the cycle and, for gas dryers equipped with a continuously burning pilot light, the cubic feet of gas consumed by the pilot light during 1 hour. In order to calculate EF according to the DOE test procedure, the following calculations are performed.

For electric clothes dryers, the total per-cycle electric dryer energy consumption, E_{ce}, is defined as:

$E_{ce} = (66/W_w - W_d) \times E_t \times FU$ where,

66 = an experimentally established value for the percent reduction in the moisture content of the test load during a laboratory test cycle, expressed as a percent
W_w = the moisture content of the wet test load
W_d = the moisture content of the dry test load
E_t = the total kWh of electrical energy measured during the test
FU = a Field Use factor
= 1.18 for time termination control systems
= 1.04 for automatic termination control systems

For gas clothes dryers, the total per-cycle gas dryer electrical energy consumption, E_{ge}, is calculated in the same manner as for electric dryers. Total per-cycle gas dryer energy consumption expressed in kWh, E_{cg}, is defined as:

$E_g = E_{ge} + [(66/W_w - W_d) \times E_{tg} \times FU \times GEF + E_{pg} \times (8760\text{-}140/416) \times GEF]/3412$ where,

E_{tg} = the cubic feet of gas used during the cycle
GEF = the corrected gas heat value (Btu/ft^3)
= 1.18 for time termination control systems
= 1.04 for automatic termination control systems
E_{pg} = the cubic feet of gas used by a continuously burning pilot light in 1 hour
8760 = the number of hours in a year
416 = the representative average number of clothes dryer cycles in a year
140 = the estimated number of hours that the continuously burning pilot light is on during the operation of the clothes dryer for the representative average use cycle for clothes dryers (416 cycles per year)

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[f] "Bone dry" means a condition of a load of test clothes which has been dried in a dryer at maximum temperature for a minimum of 10 minutes, removed and weighed before cool down, and then dried again for 10-minute periods until the final weight change of the load is 1 percent or less.

3412 = the conversion factor of Btu/kWh
The value of 66, W_w, W_d, FU, and GEF are the same as were defined for electric clothes dryers.

Finally, EF, expressed in lb per kWh, is derived from the per-cycle electrical energy consumption according to:

EF = M/ E_{ce} for electric clothes dryers
= M/ E_g for gas clothes dryers

M = the test load size in lb

Additional instrumentation was provided during these tests to measure disaggregated component energy consumption in order to assess which strategies and features could have the greatest impact on efficiency. Watt meters were attached to the following major components which together account for virtually all of the electrical energy usage of the clothes dryer:

- heating element for electric units;
- gas valve for gas units;
- drum motor;
- blower motor, if separate from the drum motor;
- controller;
- pump for ventless units, which removes condensate; and
- water valve for ventless electric combination washer/dryer.

Overall trends in key parameters of the clothes dryers under DOE testing are shown in Figure 5.6.3 and Figure 5.6.4, including average drying times and total per-cycle electrical energy consumption. Each data point represents the average of three tests. DOE also compared measured EF to rated EF for each of the clothes dryers in the test sample because manufacturers indicated during interviews that the tolerances in the existing test procedure can introduce uncertainty in the EF measurement. By ensuring the testing was conducted under consistent test conditions, DOE intended to normalize the data against allowable variations in ambient conditions and test parameters. Because the ventless clothes dryers have not been rated, the EF for these units could only be represented by the value measured during testing.

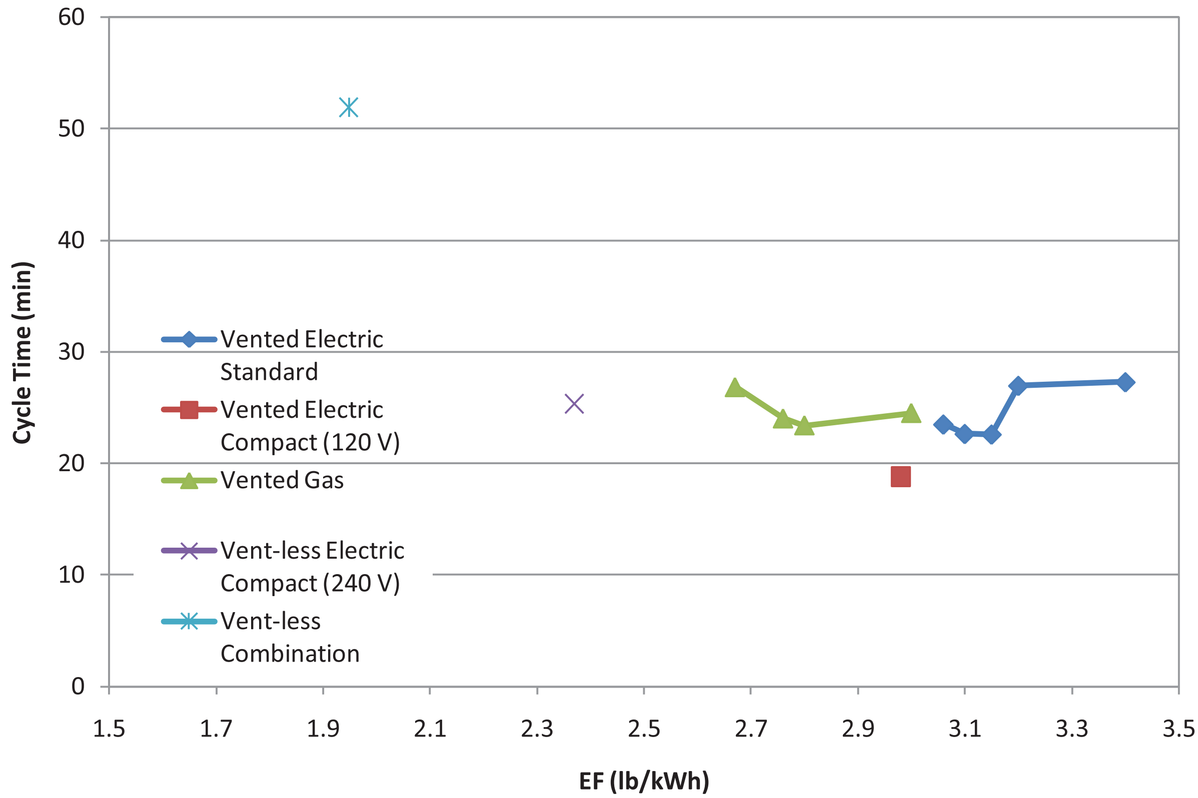


Figure 5.6.3 Measured Clothes Dryer Cycle Time versus Rated EF

These data show that cycle times for vented electric standard and gas clothes dryers are shorter between baseline and mid-efficiency units. However, in both product classes, this trend reverses at the higher efficiency levels. The data also show that, for the compact-size dryers, a ventless unit requires about 35 percent more time to dry than the vented version, although this result is likely somewhat skewed by the fact that the vented clothes dryer heating element draws about 10 percent more power than the ventless dryer's heater. Finally, these data show a significantly longer drying time associated with the ventless electric combination washer/dryer. For that particular model tested, the heating element drew less than half the power than that in the other compact clothes dryers (vented and ventless).

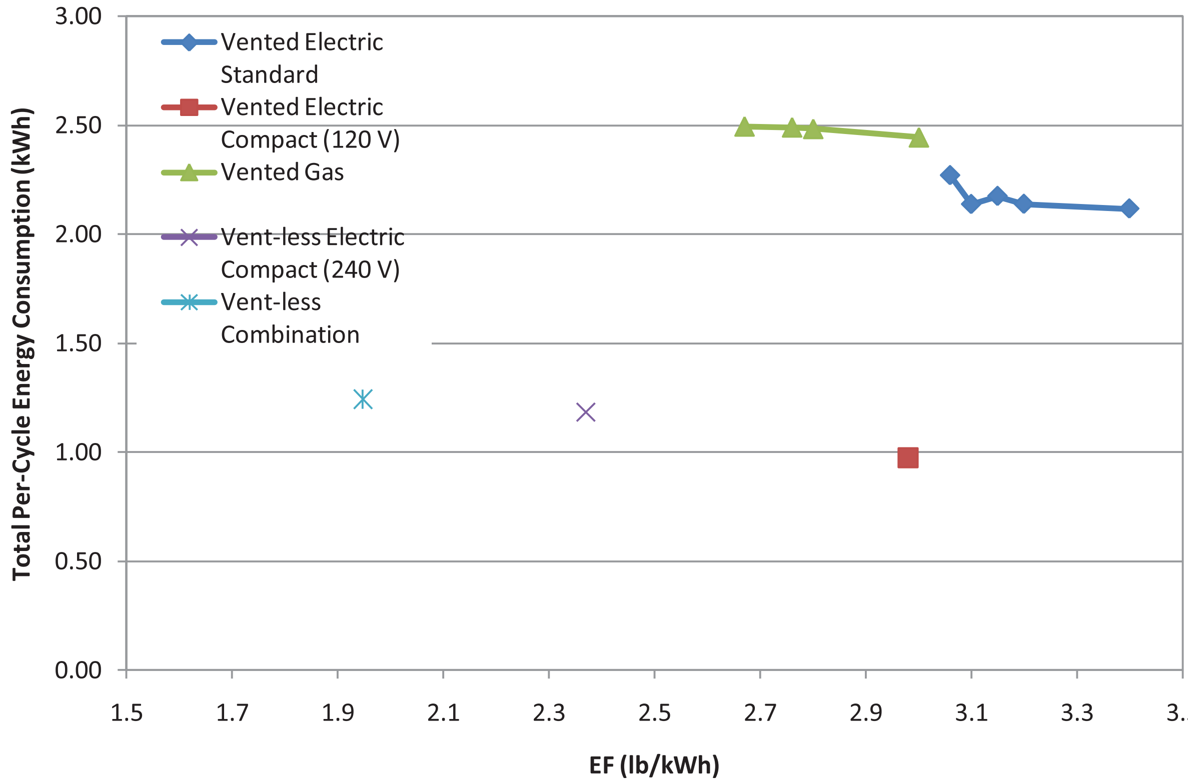


Figure 5.6.4 Measured Clothes Dryer Energy Consumption versus Rated EF

The data for total per-cycle energy consumption demonstrate the expected trend of measured energy use decreasing as a function of rated EF, again with the ventless data plotted as a function of measured rather than rated EF. The slope for compact units (which include the ventless combination washer/dryer) is fairly consistent with the slope for gas clothes dryers, with a somewhat steeper slope observed for vented electric standard clothes dryers. This potentially demonstrates uncertainty in the EF measurement, since EF should scale directly with total energy consumption. The test procedure may allow enough variation in the measurement of EF due to the specified tolerances to introduce uncertainty in the correlation between measured energy consumption and rated EF.

Such uncertainty can be explored by comparing the rated EFs, which are obtained under varying allowable conditions in multiple test laboratories, to DOE's measured EFs, which were obtained under consistent conditions in a single laboratory. Figure 5.6.5 presents the comparison for the clothes dryers for which rated EF was available, with a trend-line included to show what the correlation ideally would be. It can be seen that, for many of the units, measured EF does not correlate particularly closely with rated EF. In particular, the measured EFs for gas clothes dryers showed little variation among the four test units. In addition, the max-tech units in both vented electric standard and gas clothes dryers had measured EFs that were lower than the certification data would indicate.

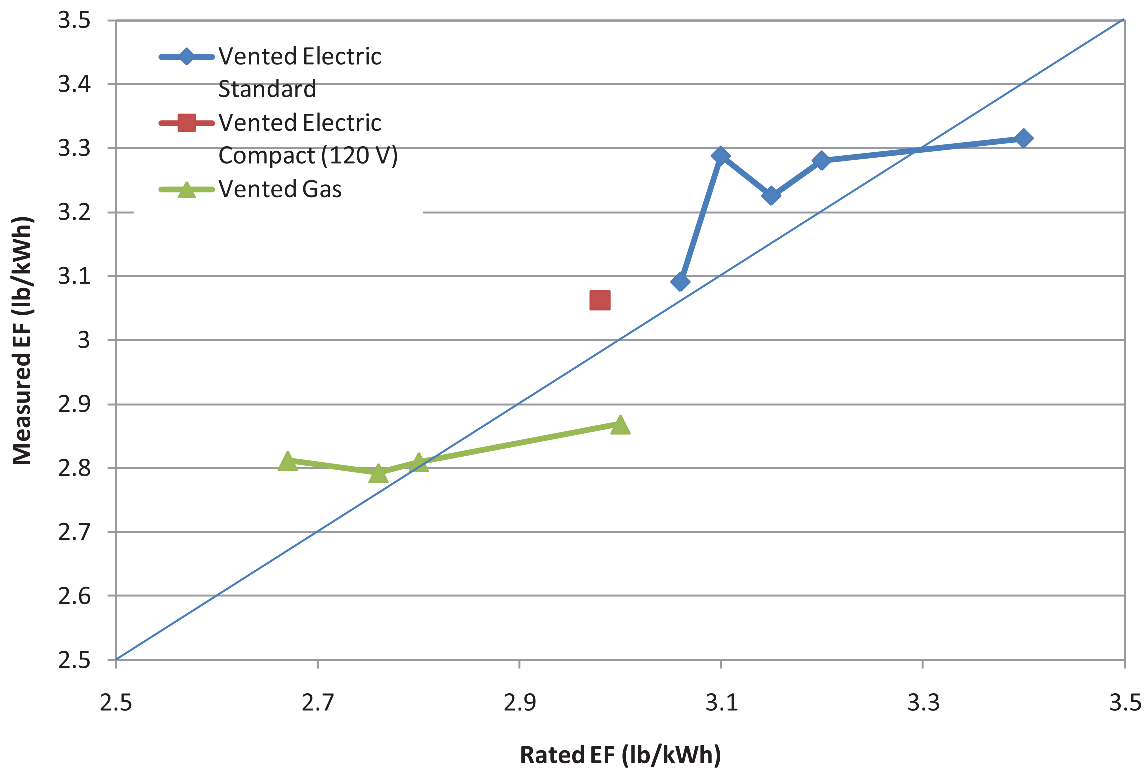


Figure 5.6.5 Measured versus Rated Clothes Dryer EF

DOE believes that the lack of strong correlation between measured and rated clothes dryer EF can be traced to the tolerances that are allowed in the test procedure, notably for the ambient test room conditions. Whirlpool Corporation (Whirlpool) submitted data to DOE that demonstrates the effect of a change in ambient relative humidity and temperature on EF. Parametric variations in relative humidity from 40 to 60 percent and ambient temperature from 72 to 78 °F, which are the limits allowed under the test procedure, produce measured EFs for an electric compact (120 V) clothes dryer that range from 2.98 to 3.35 lb/kWh. The Whirlpool data submission is reproduced in appendix 5B of this TSD. These data and their implications are currently being considered in a clothes dryer test procedure rulemaking.

Component-level data recorded from the watt meters during the DOE tests disaggregated the power consumption of individual components, allowing DOE to evaluate what strategies a manufacturer might choose to pursue higher energy efficiency. Figure 5.6.6 shows the component average power consumption while in use during the cycle for each of the test units. Within a product class, the models are arranged in the figure from lowest to highest EF. For purposes of visualization, heater power consumption and the gas use in equivalent W have been divided by a factor of 10, so that relative contributions from the other components can be compared. Also, it is recognized that the heater and gas burner are cycled on and off towards the end of the drying cycle. While the heating element watts are averages of instantaneous measurements during the periods when the heater is energized, and thus the power measurement is meaningful, the equivalent gas W are obtained from the total gas energy consumption during the cycle divided by the cycle time. Such an approach does not account for the periods during the cycle when the burner is off, but a comparison of instantaneous gas flow rates to the total cubic feet of gas used during the test shows that the assumption of constant burner usage introduces at most a 3 percent error. Therefore, it can be determined from Figure 5.6.6 that the heating element/gas burner is by far the largest contributor to per-cycle energy consumption, and therefore optimization of its usage and design will have a significant effect on efficiency. The drum motor (and potentially separate blower motor) have a second-order impact, while the gas valve, pump, and water valve (if any) are negligible in comparison.

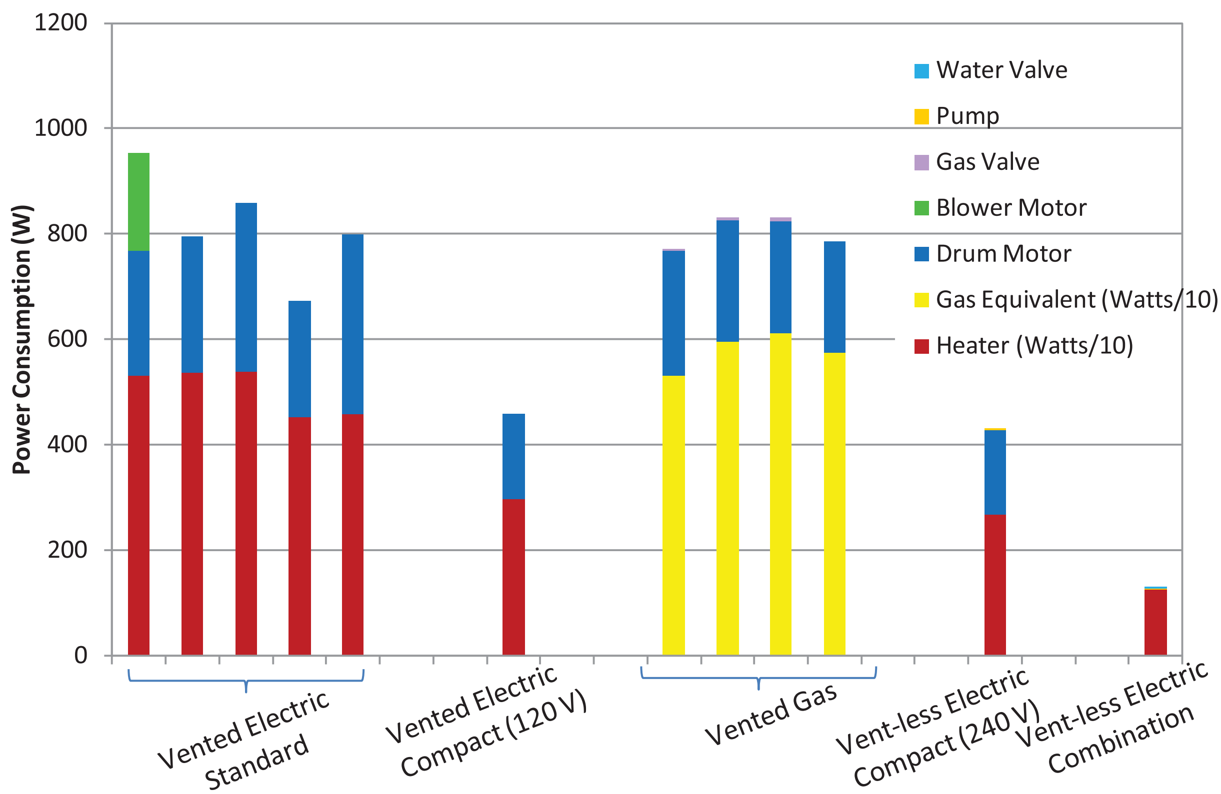


Figure 5.6.6 Disaggregated Clothes Dryer Power Consumption

It is difficult to generalize from these data what strategies manufacturers are taking to improve efficiency. Among vented electric standard clothes dryers, it appears that manufacturers are reducing heating element and motor power to achieve higher EFs, although the trend is not strong. That trend is even weaker among the tested gas clothes dryers. However, DOE notes that it did not see significant differences in measured EF among these units, so potentially the test sample did not fully capture possible design improvements.

To summarize key findings from the testing of a small number of clothes dryers, DOE observed that:

- Test procedure tolerances introduce uncertainty in the EF measurement that is significant in comparison to the EF range between a baseline and high efficiency clothes dryer.

- Improvements in the heating element or gas burner may provide a key opportunity for improving EF. A second-order impact could be achieved by improvements in the motor(s).

- Modest increases in EF over the baseline can result in reduced drying cycle times.

- Ventless electric compact (240 V) clothes dryers do not require drying times that are longer than those acceptable to consumers (*i.e.*, typical drying times associated with vented electric standard clothes dryers.

Standby Mode and Off Mode Testing

For the preliminary analysis, DOE measured standby and off mode power for 10 of the 12 clothes dryers in the test sample, using methodology provided in the International Electrotechnical Commission (IEC) Standard 62301 Ed. 1.0 (2005-06), *Household electrical appliances – Measurement of standby power*. The remaining two clothes dryers, both ventless units, incorporated components contributing to standby power that were energized by 240 V line power that could not be measured with the standby power meter used for these tests. Data obtained from this testing are presented in section 0.

RMC Testing

DOE also conducted tests for four representative clothes dryers (one each of vented electric standard, vented electric compact (120 V), vented gas, and ventless electric compact (240 V) product classes) to evaluate the impact of changes in initial RMC on measured EF, supplementing the RMC data AHAM submitted. The units were each tested at three different initial RMC levels: (1) nominally 70 percent, representing the conditions specified in the current DOE test procedure; (2) nominally 56 percent, to compare directly with the AHAM data submittal; and (3) nominally 39 percent, which was selected to be close to the weighted-average RMC of front-loading residential clothes washers currently on the market.

Results of these tests, with EF calculated according to the formula provided in the DOE test procedure, are shown in Figure 5.6.7. In general, reducing initial RMC produced a decrease in measured EF for all product classes. Average percentage reductions in EF as a function of initial RMC are summarized in Table 5.6.7.

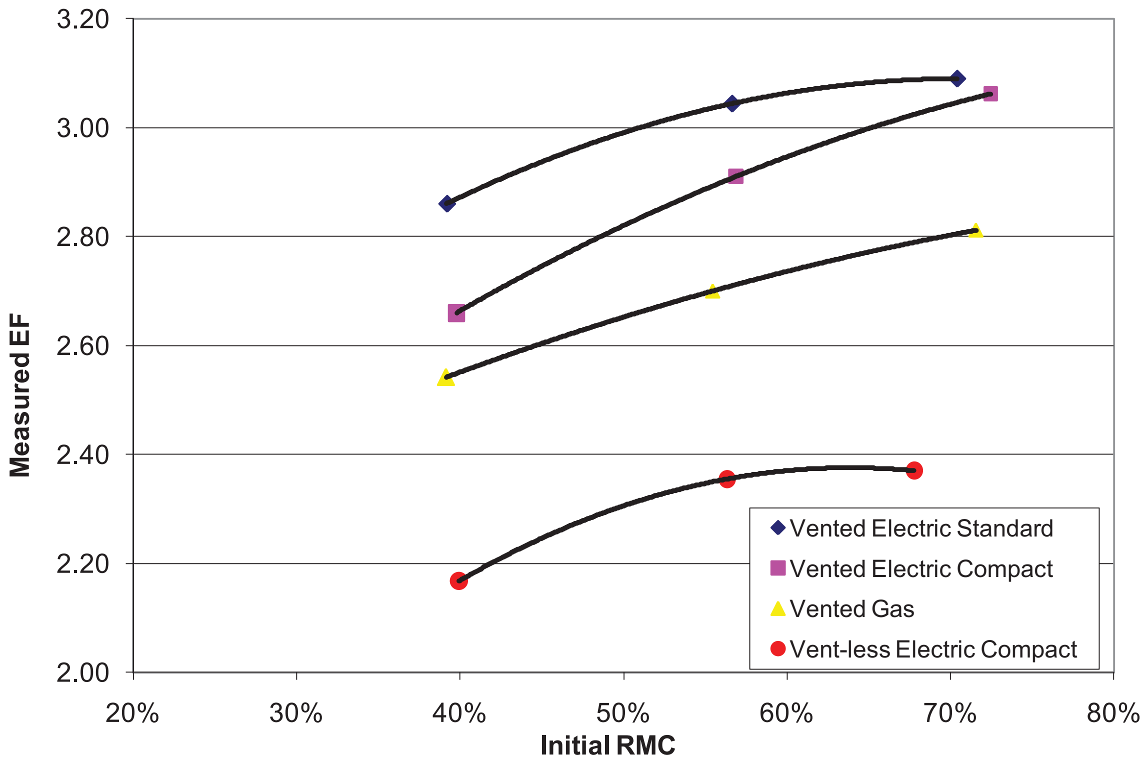


Figure 5.6.7 Impact of Initial RMC on Clothes Dryer EF (Calculated According to the Existing DOE Test Procedure)

However, as discussed in section 5.6.1.1, the scaling factor of 66 in the current DOE test procedure is intended to normalize the calculated EF, for which initial and ending RMCs can vary slightly within allowable tolerances, to a reduction in RMC over the course of the test from 70 percent to 4 percent. For tests in which the nominal starting RMC is no longer 70, DOE believes that the scaling factor may not be meaningful. Therefore, DOE subsequently calculated the EFs for the test units using scaling factors at each starting RMC that reflected a change from that RMC to 4 percent. For example, for a starting RMC of 56 percent, the scaling factor would be 52 (56 percent initial RMC minus 4 percent ending RMC). The results using adjusted scaling factors are presented in Figure 5.6.8.

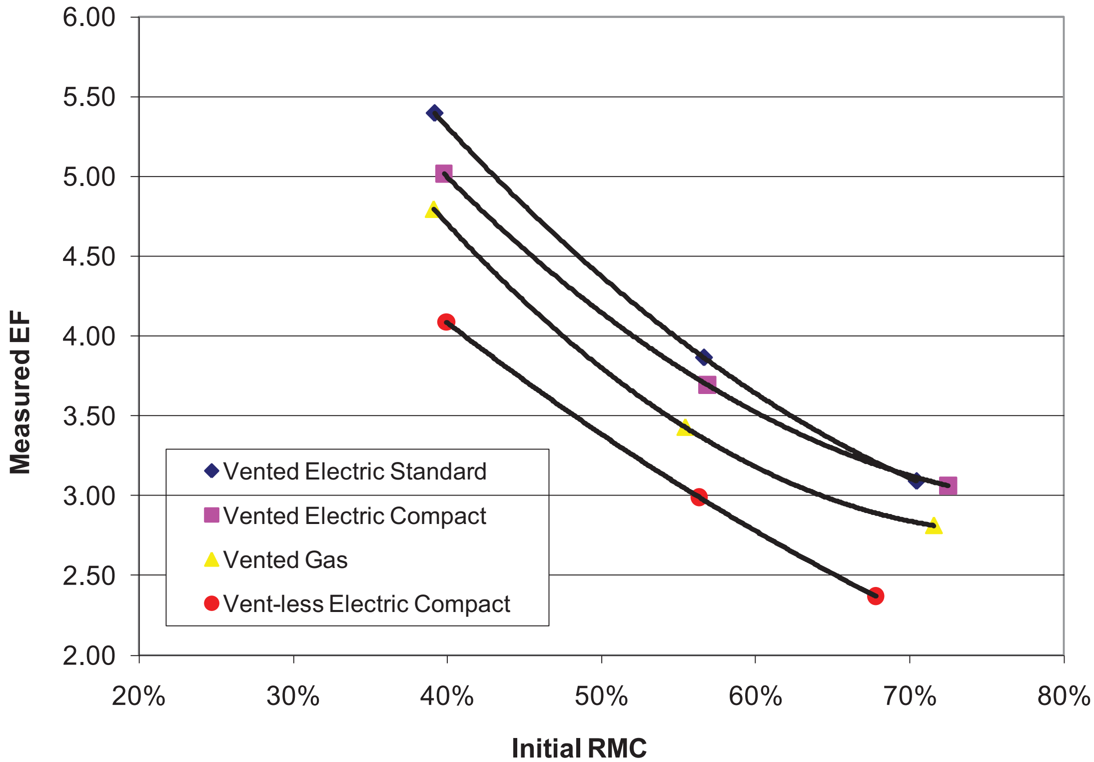


Figure 5.6.8 Impact of Initial RMC on Clothes Dryer EF (Calculated Using Adjusted Scaling Factors)

Using the revised scaling factor methodology, DOE determined that reducing the initial RMC increased EF significantly, as shown in Table 5.6.7.

Table 5.6.7 Average Change in Clothes Dryer Energy Factor as a Function of Initial RMC as Compared to Initial RMC of 70 Percent

Initial RMC %	Change in EF using Existing Scaling Factor (%)		Change in EF using Adjusted Scaling Factor (%)	
	DOE Results	AHAM Results	DOE Results	AHAM Results
56	-3	-4	23	22
39	-10		70	

At the time of the preliminary analysis, DOE was considering amendments to its clothes dryer test procedure to revise the initial RMC to reflect the performance of residential clothes washers currently on the market, but had not yet published a NOPR proposing active mode test procedure amendments. Therefore, in the preliminary analysis, DOE did not analyze energy conservation standards based on initial RMCs lower than the existing 70 percent.

Maximum-Available Vented Gas Clothes Dryer Testing

After the framework document was published, DOE determined several models of vented gas clothes dryers were listed in the CEC product database with an EF (based on the previous DOE test procedure) above the maximum-available efficiency level proposed in the framework document. As discussed in section 5.6.1.5, multiple manufacturers stated during interviews that the current maximum efficiency that is listed for vented gas clothes dryers in the CEC product database is not achievable. Therefore, DOE tested the model that was rated as the maximum-available efficiency vented gas clothes dryer to help determine an appropriate max-tech level value for the preliminary analysis. DOE purchased three identical units of this model and tested each three times according to the previous DOE clothes dryer test procedure. Table 5.6.8 shows the results from this testing, which indicate that the maximum-available model was measured as having an EF significantly lower than its rated value. Therefore, DOE did not consider this EF value for the max-tech level analysis.

Table 5.6.8 Results from DOE Testing of Maximum-Available Vented Gas Clothes Dryers

Unit	Measured Average EF *(lb/kWh)*	% Difference from CEC Product Database Value (3.44 EF)
1	2.83	-17.7
2	2.75	-20.1
3	2.82	-18.0

5.6.1.3 Product Teardown

As part of its reverse-engineering process, DOE tore down clothes dryers to identify design features, and corresponding manufacturing costs, that are associated with successively higher efficiency levels. The clothes dryer teardown analysis performed for this engineering analysis included the 12 teardown units total for four of the five product classes selected for the preliminary analysis, excluding only vented electric compact (120 V) clothes dryers due to lack of availability. For the other vented product classes, DOE selected products such that within that class, the chosen models span the range of EF from baseline to max-available.

DOE first notes that all of the clothes dryers it examined are constructed with an outer sheet metal assembly comprising panels that had been formed by stamping, joined, and painted. This assembly houses the cylindrical drum, drive motors, heater systems, and the associated ducting. Details of these components and sub-assemblies are as follows.

Baseline Construction

For the baseline vented units, the bottom base plate of the cavity holds a single 1/4–1/3 horsepower (hp) induction motor which drives both the drum and the blower. For gas clothes dryers, the bottom base plate also holds the gas burner system, which consists of a single stage gas valve, venturi, and gas inlet pipe. A conical duct then directs the hot air generated from the gas burner towards the back of the cabinet, where it flows through a duct to the rear of drum. For the baseline electric standard clothes dryers, the heating system consists of an electrical resistance heater which is contained in a duct which covers the back wall of the drum.

For the baseline unit construction, the laundry basket consists of a metal cylinder which has a circular plate attached on the rear to form a drum. The drum is driven by the single induction motor (installed on the bottom base plate) and a drive belt. The drum rotates about a shaft mounted on the plate on the rear of the drum. On the front edge of the drum, the drum spins on smooth plastic strips mounted to the front face of the cavity.

The hot air from both gas and electric heating systems enters from behind the drum, passes through the clothes load, and exits the drum near the front door. The moist air is then pulled through the lint filter and through the blower fan, which is driven by the same single induction motor that rotates the drum. Subsequently, the moist flue air exits through the exhaust pipe leading out the rear of the exterior sheet metal assembly.

The baseline clothes dryer is also equipped with electromechanical controls which allow the user to select specific cycle settings. DOE also noted in its teardown of baseline units and through surveys of products available on the market that baseline clothes dryers feature automatic cycle termination using temperature switches and timer controls. All baseline clothes dryers torn down feature temperature switches in the heater duct and blower/exhaust duct sections.

The baseline ventless electric compact (240 V) clothes dryer has a similar construction to the baseline vented electric clothes dryer, with the following differences. A baseline ventless clothes dryer is equipped with a permanent split capacitor (PSC) motor which drives both the drum and the blower fan. The drum rotates about a shaft mounted on the plate on the rear of the drum; however, the front edge of the drum spins on two roller wheels mounted to the front face of the cavity. DOE also noted in its teardown that a baseline unit features electronic controls as well as automatic cycle termination using temperature sensors.

The baseline ventless electric compact (240 V) electrical resistance heater is in a dedicated duct mounted behind the rear of the drum. The hot air from the heating system enters from behind the drum, passes through the clothes load, and exits the drum near the front door. The moist air is then pulled through the lint filter and through the blower fan, whereupon the air flows through a duct mounted to the base of the cabinet containing an air-to-air cross-flow heat exchanger. Moisture in the warm, moist air condenses as the air flows past the heat exchanger towards the back of the cabinet, where it again enters the dedicated electric heater duct and repeats the airflow cycle. As part of the heat exchanger system, an additional blower fan is mounted to the single PSC motor, which pulls ambient air from the surroundings and blows it past the air-to-air heat exchanger in a direction perpendicular to the dry cycle air flow. The heat exchanger duct also houses a drain pump, which pumps the condensed moisture from the heat exchanger out of the cabinet.

The construction of the baseline combination washer/dryer is more complex than that of a conventional clothes dryer since it is able to run both washing and drying cycles in a single cabinet using a single drum. The wash basket is contained in a tub, which prevents water from escaping into the cabinet. The tub is mounted on four shock absorbers, which in turn are mounted to the base of the cabinet. Mounted to the bottom of the tub is a large cement block, which dampens vibrations from the wash and spin cycles. An induction motor spins a drive wheel mounted on the back of the tub via a belt. This induction motor is capable of the high rotational speeds required for spin cycles. The wash basket, comprising a metal cylinder which has a circular plate attached on the rear, rotates about a shaft mounted to the rear of the drum. The drive system also uses two large ball bearings for the drive wheel and the rear drum shaft.

A PSC motor is also mounted to the bottom of the tub, which drives a blower fan contained in a dedicated duct mounted to the rear of the tub via a drive belt. The air is blown from this duct to a duct mounted to the top of the tub, which contains the electrical resistance heater. The hot air flows from the heater duct into the front of the tub, passes through the clothes load, and exits through the rear of the tub into a space between the wash basket and the tub. The air is then pulled back through the dedicated blower fan duct and the airflow cycle repeats.

The combination washer/dryer is also different from a conventional dryer in that it does not use a lint filter. DOE also noted in its teardown that the baseline unit features electronic controls, but that it does not have an automatic termination feature.

Based upon product teardowns, DOE developed the following baseline production cost distributions and materials costs distributions, shown in Figure 5.6.9 through Figure 5.6.18. Depending on the manufacturer and the production volume, the depreciation costs may vary from those shown in the figures, which assume a “green-field” site. For product classes such as vented electric compact (120 V and 240 V), ventless electric compact (240 V) and ventless combination washer/dryers, DOE assumed much smaller production volumes than for vented electric standard and vented gas dryers.

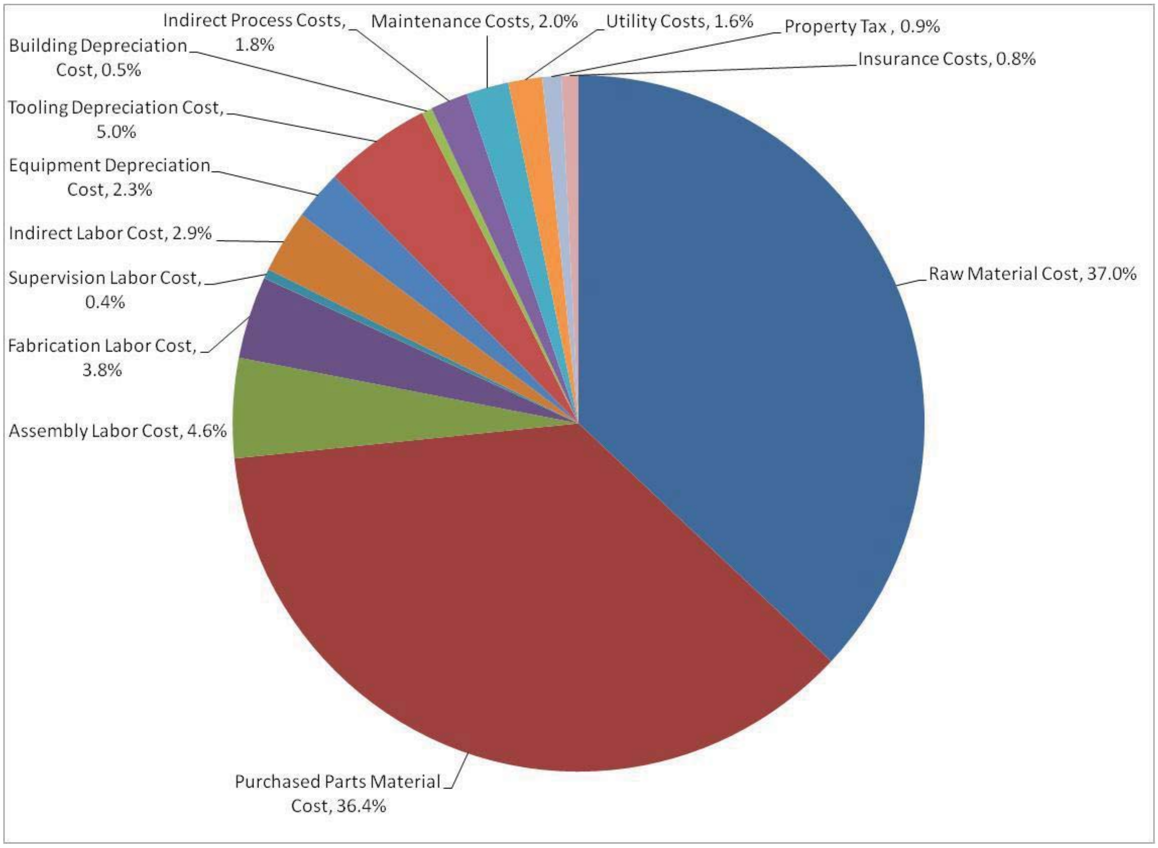


Figure 5.6.9 Baseline Vented Electric Standard Clothes Dryer Full Production Cost Distribution

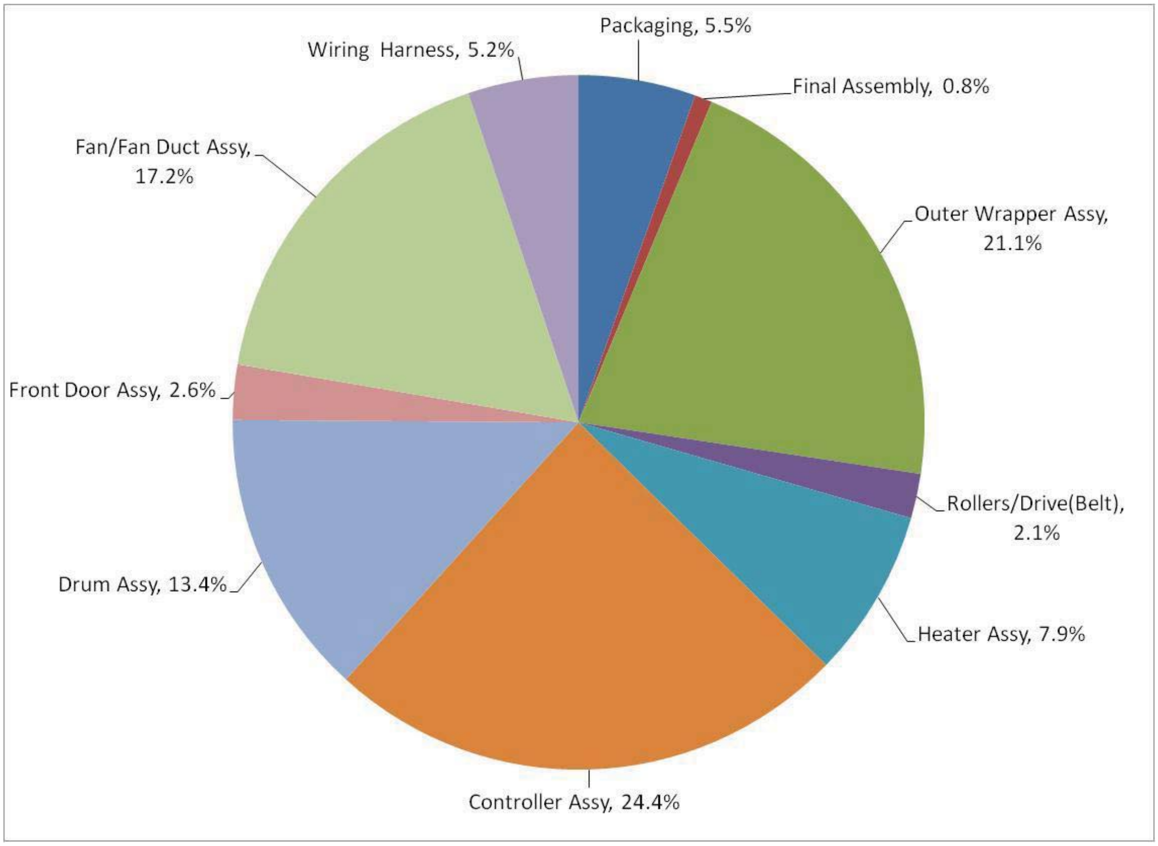


Figure 5.6.10 Baseline Vented Electric Standard Clothes Dryer Materials Cost Distribution

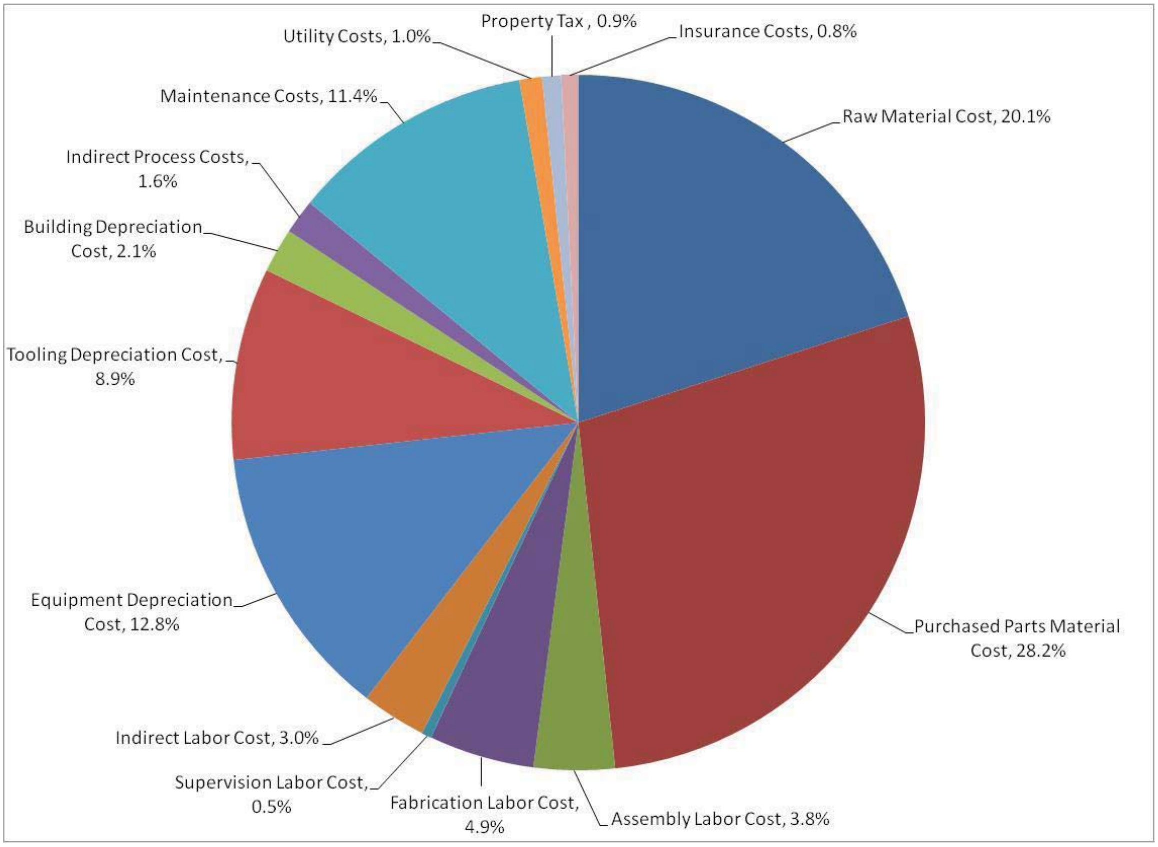


Figure 5.6.11 Baseline Vented Electric Compact (240V) Clothes Dryer Full Production Cost Distribution

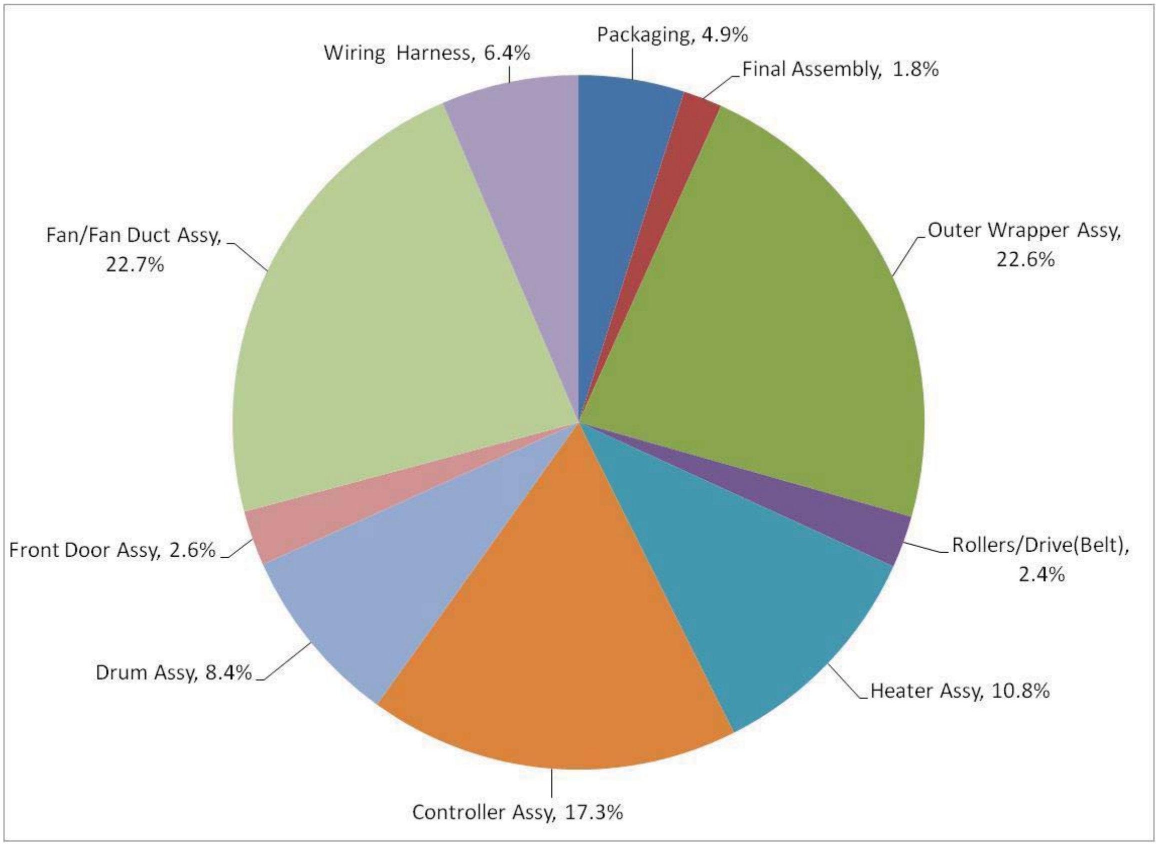


Figure 5.6.12 Baseline Vented Electric Compact (240V) Clothes Dryer Materials Cost Distribution

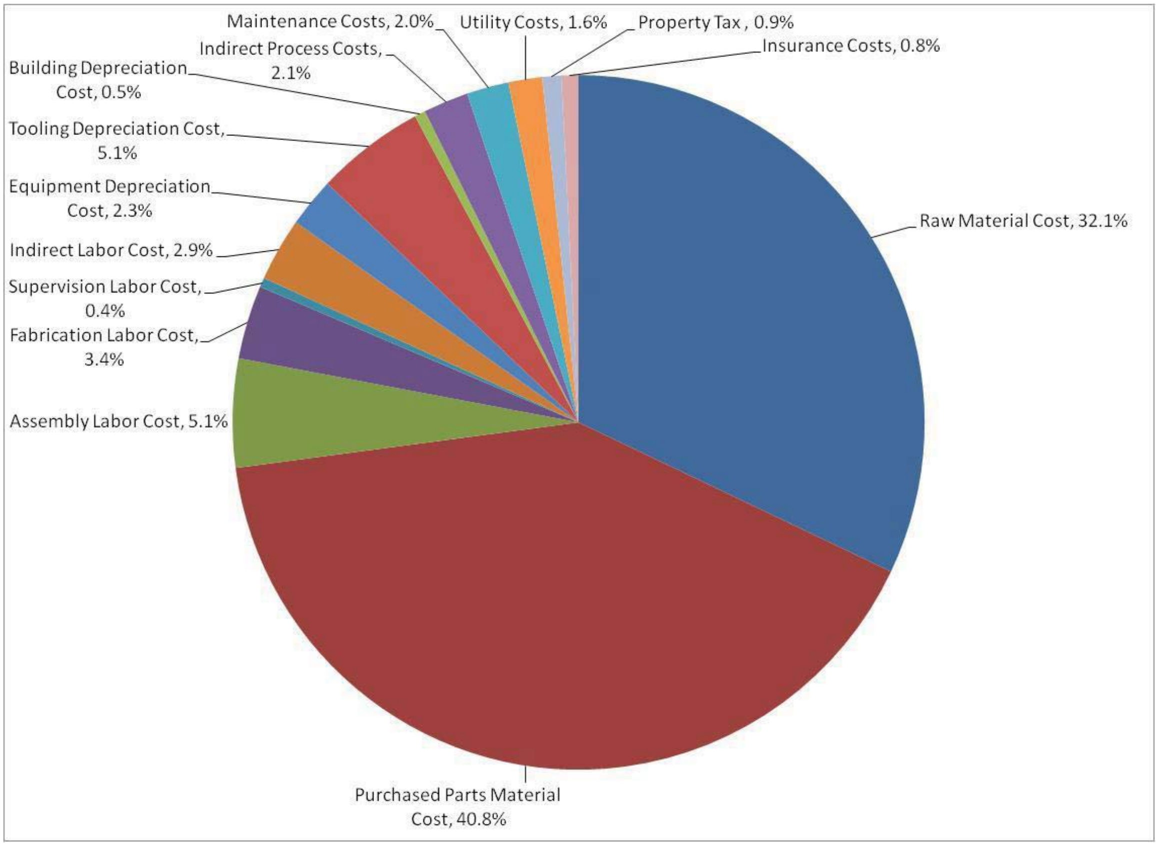


Figure 5.6.13 Baseline Vented Gas Clothes Dryer Full Production Cost Distribution

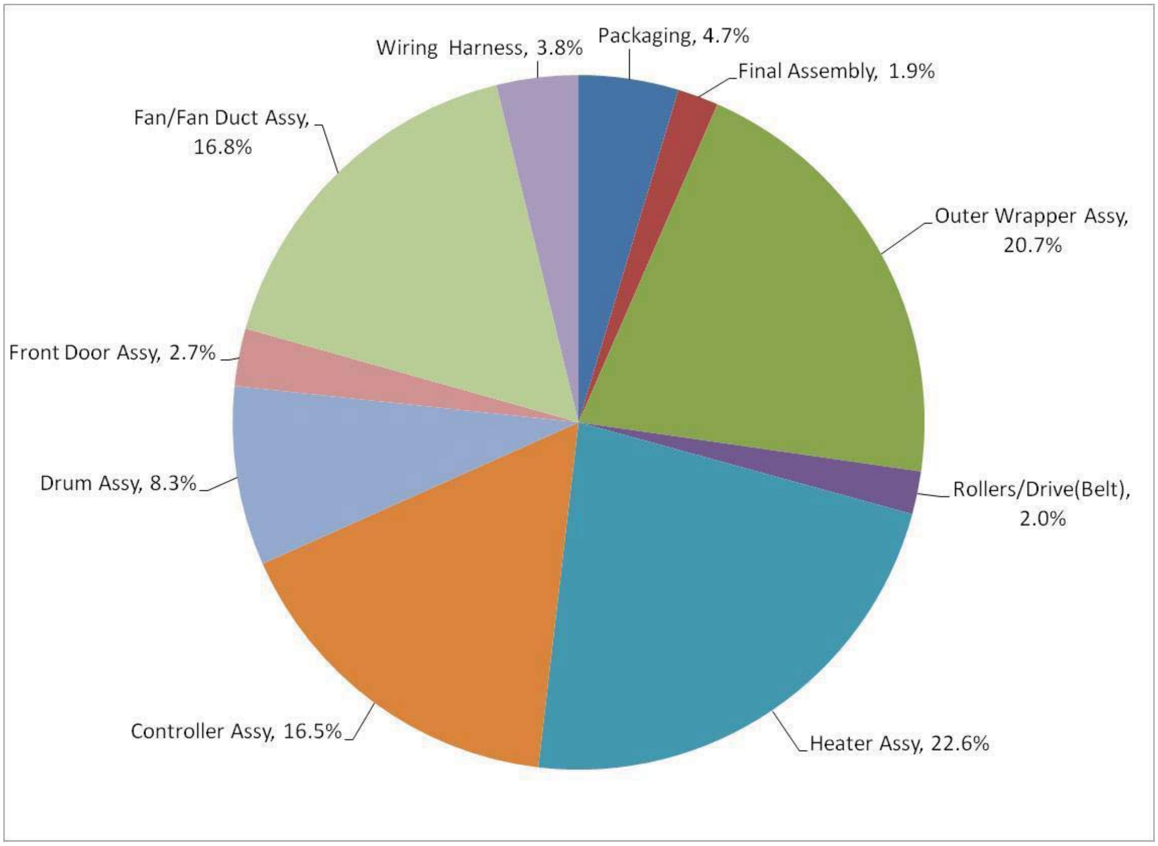


Figure 5.6.14 Baseline Vented Gas Clothes Dryer Materials Cost Distribution

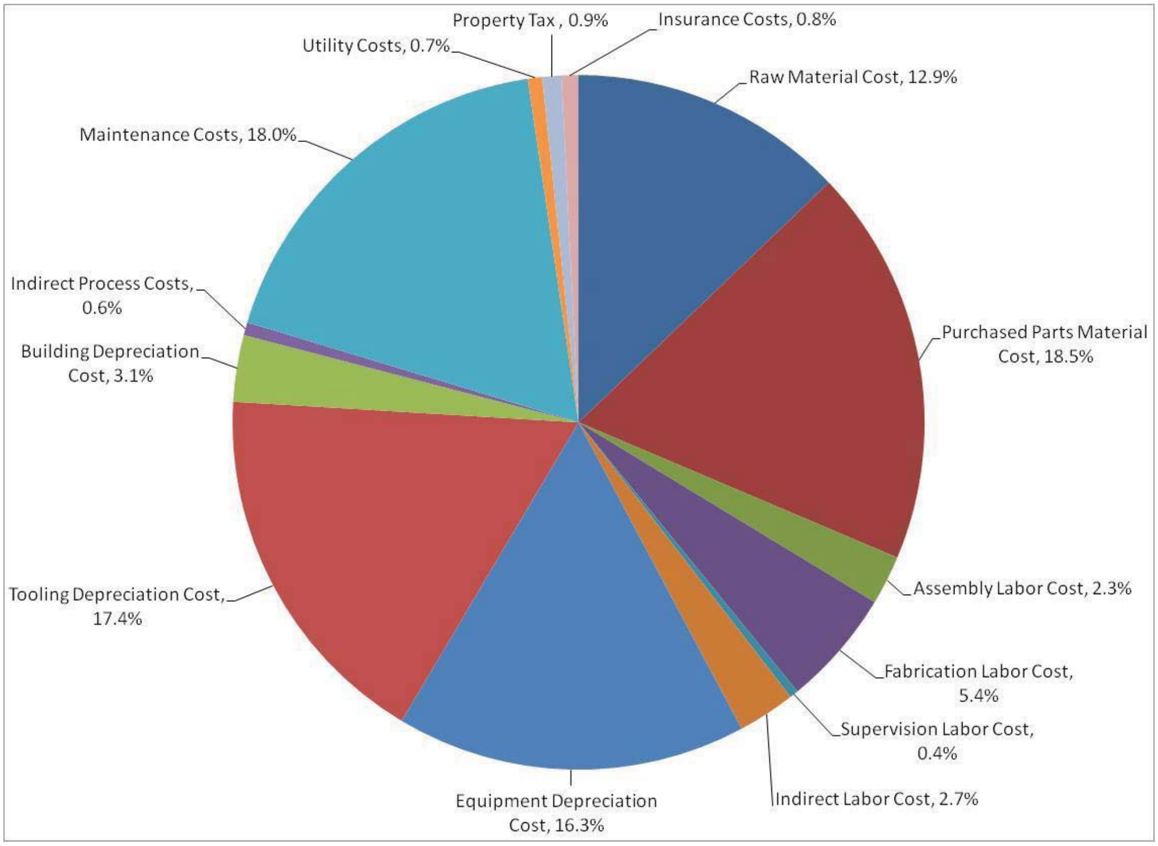


Figure 5.6.15 Baseline Ventless Electric Compact (240V) Clothes Dryer Full Production Cost Distribution

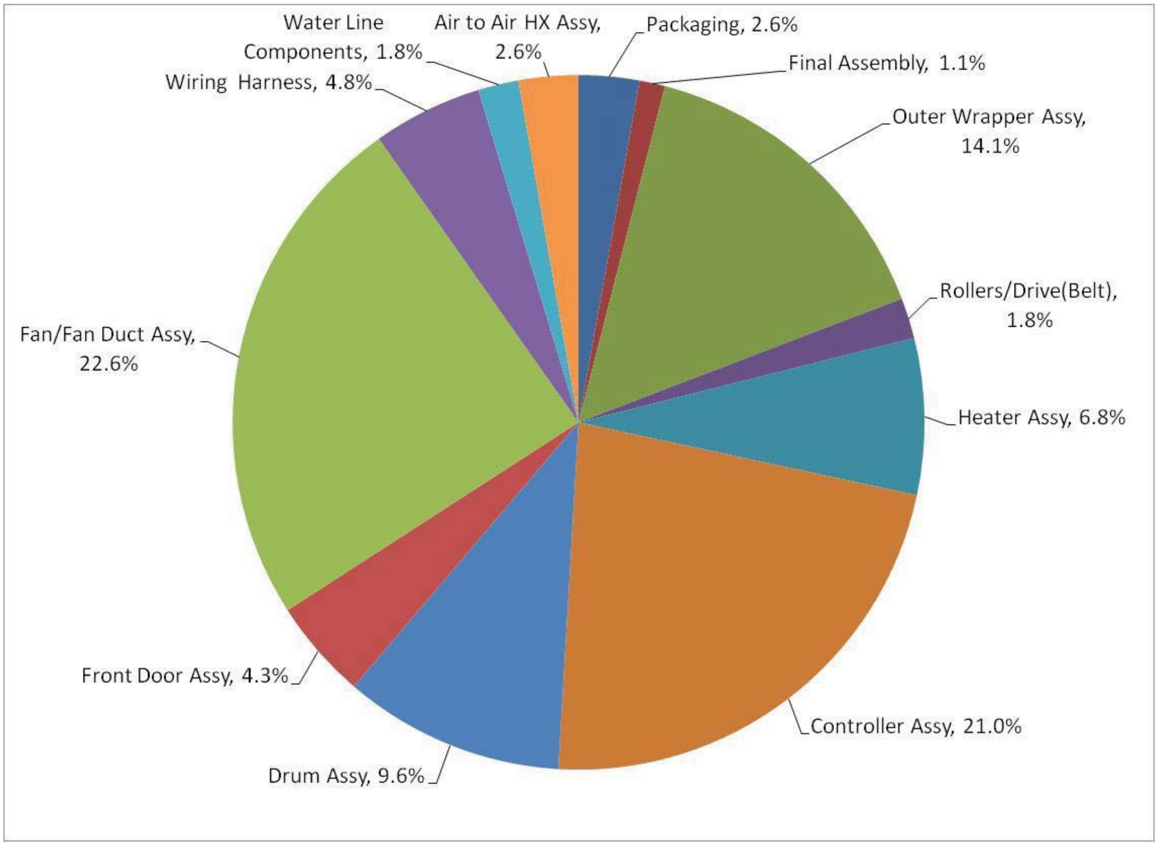


Figure 5.6.16 Baseline Ventless Electric Compact (240V) Clothes Dryer Materials Cost Distribution

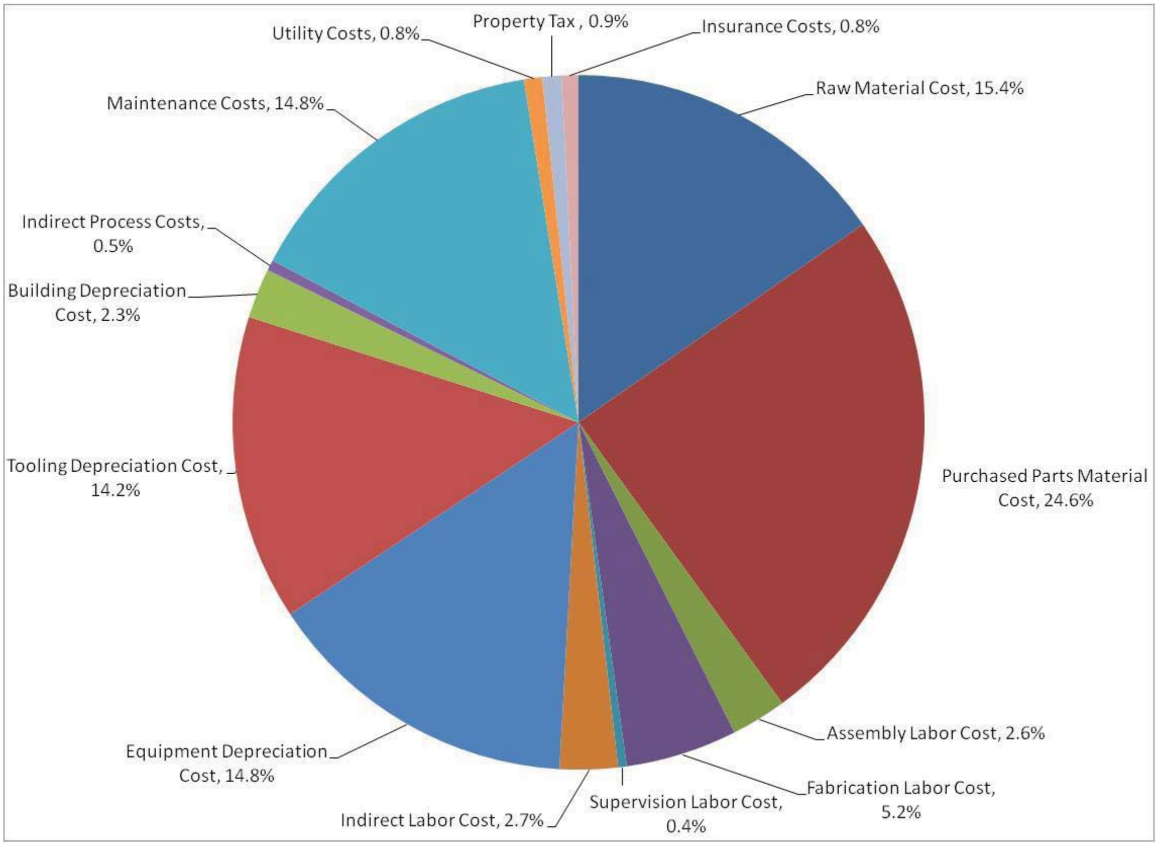


Figure 5.6.17 Baseline Ventless Combination Washer/Dryer Full Production Cost Distribution

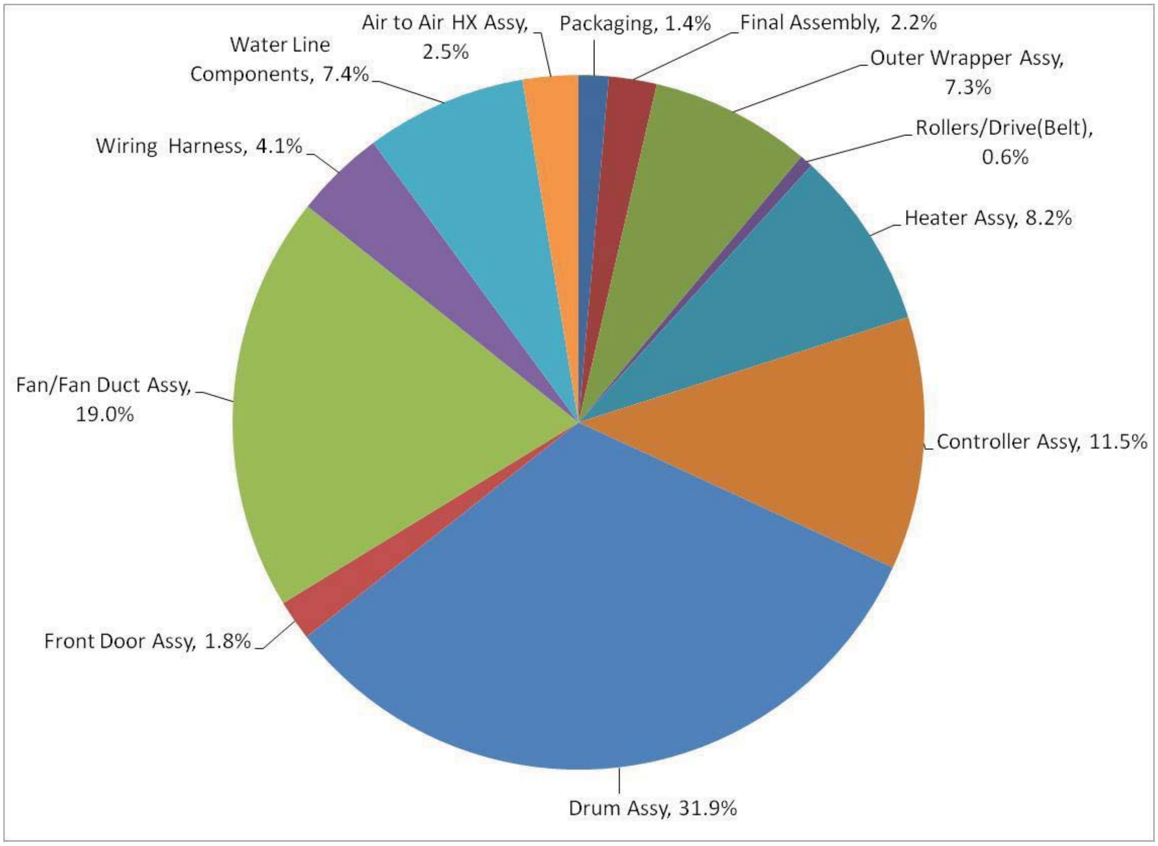


Figure 5.6.18 Baseline Ventless Combination Washer/Dryer Materials Cost Distribution

Construction at Higher Efficiency Levels

Based on the design options retained from the screening analysis (see chapter 4 of this preliminary TSD), the reverse engineering analysis, and discussions with manufacturers, summarized in section 5.6.1.5 and 5.6.1.6, DOE developed manufacturing costs associated with various design features necessary to achieve higher efficiencies.

The following are the design changes DOE believes would be necessary to meet each efficiency level, which were subsequently modeled to obtain incremental manufacturing cost estimates.

Vented Electric Clothes Dryers

Efficiency Level 1

Based on characteristics of units selected for teardown and based on discussions with manufacturers, DOE research suggests that EL 1 is achieved in vented electric clothes dryers through three changes:

1. Switching to Open Cylinder Drum

This design change can allow better air flow through the drum. The drum suspension system is also changed to a roller wheel design with wheels at the front and back edges of the drum as the bearing system in order minimize frictional losses and decrease the load on the motor.

2. Dedicated Heater Duct

The hot air flow duct that directs the air into the drum through the back would be changed from the baseline duct to a dedicated duct which directs air flow more directly into the drum and reduces heat losses.

3. Change in Air Flow Patterns

The air flow through the drum would change from a baseline back to front air flow, to flowing in through one side of the back and exiting on the other. This design change requires an outlet duct from the drum that attaches to the rear of the drum, which then leads to the blower duct and the exhaust duct. DOE notes that the costs associated with these design options will differ for standard-size and compact-size dryers because of the different amounts of materials required for structural design changes.

Efficiency Level 2

For the preliminary analysis, DOE stated that it believed that for EL2, manufacturers would apply the same design changes as used for EL 1 and additionally incorporate inlet air preheating, which requires better airflow and moisture control. However, based on further research and more recent discussions with manufacturers, DOE believes that for EL2, manufacturers would apply the same design changes as used for EL1, but additionally incorporate 2-stage modulating heat, which would require moisture sensing and multi-speed airflow

1. 2-Stage Modulating Heat

For this design change, the conventional single electric resistance heater would be replaced by two smaller-sized electric resistance heaters to allow for 2-stage control of the heat output. The resistance heaters would be controlled by the control board that also reads the moisture (discussed below), and would require and additional relay to control the additional heater.

2. Moisture Sensing and Multi-Speed Airflow

Moisture sensing requires a separate measurement and control board, which can be used in conjunction with electromechanical controls. Since baseline motors drive both the drum and the fan, variable airflow requires the adoption of dedicated drum and fan blower motors. Both motors would likely be PSC-style motors, with the drum motor featuring single-speed and the blower motor triple-speed operation to match the heat output of the 2-stage heater. The speed of the blower motor would be controlled by the control board that also reads the moisture.

Efficiency Level 3

For the preliminary analyses, DOE stated that manufacturers would likely add fully modulating heat to the platform described for EL 2 to achieve EL 3, without inlet air-preheating. Because DOE is not aware of any gas clothes dryers with fully modulating burner systems currently on the market, DOE did not consider this technology further in developing the standards set forth in today's direct final rule. DOE does include this technology as a longer-term means to achieve energy efficiency improvements in a sensitivity analysis described in chapter 16 of this TSD. Based on further research and more recent discussions with manufacturers, DOE believes that for EL 3, manufacturers would apply the same design changes as used for EL 2 and additionally incorporate inlet air preheating, which requires better airflow and more advanced control systems.

1. Inlet air pre-heating

Inlet air pre-heating requires an air-to-air heat exchanger (with added ducting) in order to recover exhaust heat energy with which to preheat inlet air. To prevent condensation, moisture sensors and variable-speed blowers are required to adjust airflow rates and to allow for more accurate control of the drying cycle. The control system would have to be upgraded to electronic controls to allow for more accurate control of the airflow, heaters, and sensors.

2. Variable Airflow

A variable-speed fan motor is likely required to seamlessly match the heat output of the heater coil and the rate of heat recovery from the inlet air pre-heating to prevent condensation. Typically, manufacturers incorporate electronically-commutated motors or equivalent motor designs for such applications. Such a motor is also more efficient than the standard induction motor of PSC motor, which results in a slight increase of the overall efficiency of the clothes dryer.

Efficiency Level 4

DOE research suggests that EL 4 would require the use of heat pump technology. As a starting point, this level would incorporate most features described for EL 2. Two features would likely be omitted, however: the airflow rerouting described in EL 1 as well as the pre-heater described in EL 2. Other required design features would be a more sophisticated control system, an upgraded air flow system, a booster heater, and a condensate removal system.

1. Heat Pump System

The heat pump system would be made up of a reciprocating compressor, evaporator, condenser, and sealed system components. Existing heat pump clothes dryer design schematics suggest the use of tube and fin heater exchangers with wide evaporator fin spacing to prevent lint foiling. In order to handle the variation in heating load throughout the drying cycle, a thermostatic expansion valve is used to control the refrigerant flow. Standard-size and compact-size dryers would require different material costs for this design option because of the different sizes of the heat exchangers and shipping packaging.

2. Electronic Controller, Thermal and Moisture Sensing

A heat pump dryer would likely require sophisticated moisture, airflow, and temperature control to maximize the energy savings. Thus, an electronic controller, moisture sensors, and multiple thermal sensors are incorporated into this efficiency level.

3. Upgraded Airflow System

A heat pump dryer is expected to require dedicated fan and drum motors, as described in EL 2. However, the additional pressure drop imposed by ducting, heat exchangers, etc. will likely double the shaft power requirements of the fan motor. The size and wire density of the lint filter would also need to be increased to prevent lint migration past the filter to the heat exchanger.

4. Booster Heater

Because of the long warm-up times associated with a heat pump system, and the consumer demand for shorter dry cycles, DOE believes that manufacturers could incorporate a booster heating element. This heating element would be undersized compared to the conventional heating element and would run only during the warm-up phase.

5. Condensate Removal

Since a heat pump dryer produces condensate, a condensate removal system is expected to be standard feature in a heat pump dryer, just as it is in condensing dryers.

Gas Clothes Dryers

DOE believes that the same fundamental design changes described above for vented electric standard dryers for EL 1 through EL 3 would be applied to vented gas clothes dryers. Because of inherent differences in the designs between gas and electric clothes dryers (*e.g.*, different ducting, heat sources, etc.), the costs at each efficiency level are not identical. Most notably for EL 2, the 2-stage modulation of gas heat requires significantly different component changes as compared to 2-stage modulating electric heat.

For EL 2, DOE believes that manufacturers would switch from the baseline single-stage gas valve to a 2-stage modulating gas valve. DOE notes that gas-fired clothes dryers with 2-stage modulating gas valves are available on the market today. Additional controls would be required to control the gas valve modulation. As with the EL 2 design changes for electric standard dryers, the same disaggregated motor design (with additional controls) would also be incorporated into this level.

Ventless Electric Compact (240 V) Clothes Dryers

DOE believes that essentially the same changes described above for vented electric clothes dryers for EL 1, EL 2, and EL 4 would be applied to ventless electric compact (240 V) clothes dryers. However, because the baseline unit already contains a dedicated heat duct, only the remaining design options for vented electric clothes dryer EL 1 would need to be applied to EL 1 for this product class. Also, because the EL 3 design changes applied to vented electric clothes dryers were based upon inlet air preheating, these design changes would not be applied to a ventless electric compact (240 V) clothes dryer because it already recirculates the air back through the system. For this reason, the EL 2 and EL 4 design changes for vented electric clothes dryers are applied as EL 2 and EL 3, respectively, for this product class. DOE also notes that the baseline ventless electric compact (240 V) clothes dryer already contains electronic controls; therefore, certain design options such as moisture sensing and variable speed motor control will require a smaller incremental manufacturing cost.

Ventless Electric Combination Washer Dryer

Because the baseline unit in this product class does not have automatic cycle termination, DOE believes that EL 1 would be achieved by incorporating such a feature. Because the baseline unit already has a number of temperature sensors as well as electric controls, the changes required to implement an automatic cycle termination feature would likely be minimal, consisting primarily of an additional temperature sensor in the exhaust air as well as control logic reprogramming.

Because of the complex construction of the baseline combination washer/dryer, DOE believes that the design changes for EL 2 for vented electric clothes dryers (*i.e.*, inlet air preheating) could not be applied to this product class. Further, for the reasons described above for ventless electric compact (240 V) clothes dryers, DOE believes that the EL 2 and EL 4 design changes for vented electric clothes dryers would be applied to EL 2 and EL 3, respectively, for this product class. Again, because the baseline unit already incorporates a two motor design, as well as electronic controls, the incremental manufacturing costs will be smaller for this product class as compared to vented electric clothes dryers.

Standby Mode Construction

As part of the reverse engineering analysis, DOE investigated the design options and incremental manufacturing costs for decreasing standby power consumption. DOE developed the following design pathways for the standby levels identified in section 5.4.2.2.

DOE's analysis suggests that SL 1 can be achieved by implementing a switch-mode power supply in place of a conventional linear regulated control board power supply. DOE observed a number of clothes dryers which incorporated switching power supplies. DOE's teardown analysis also suggests that SL 2 can be achieved by implementing a transformerless power supply along with a conventional power supply. Such a power supply design, incorporated with a "soft" power pushbutton and electromechanical relay, would provide just enough power through the transformerless power supply to maintain the microcontroller chip while the clothes dryer is not powered on. When the power button is pressed, the control logic enables a Triode for Alternating Current (Triac) to enable power to the transformer of linear power supply. Hence, the Triac isolates the linear power supply from the mains until it is needed to power relays, the user interface, etc. Through this means, the standby power issues typically associated with linear power supplies can be eliminated.

5.6.1.4 Cost-Efficiency Curves

Active Mode

Based upon product teardowns and cost modeling, DOE developed the following cost-efficiency relationships for each product class, shown in

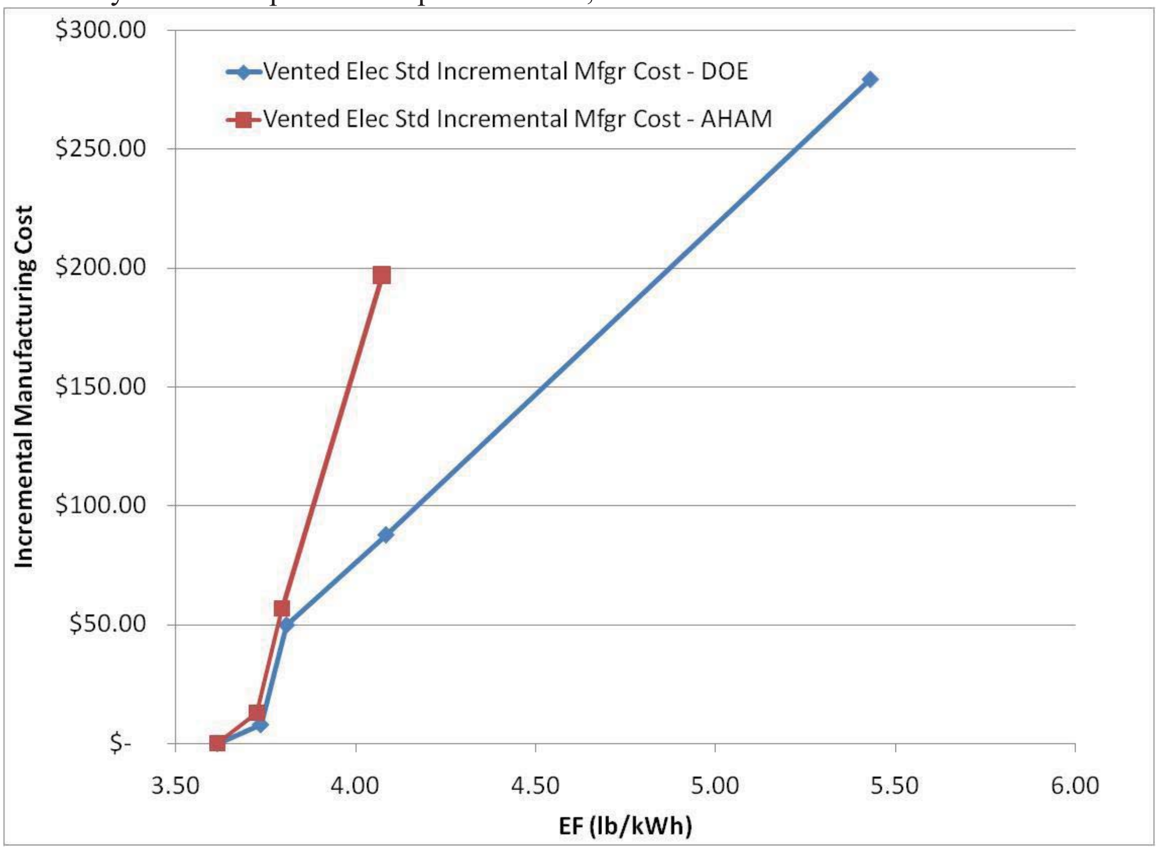


Figure **5.6.19** through Figure 5.6.24 and Table 5.6.9 through Table 5.6.14. DOE updated the manufacturing cost model data developed for the preliminary analysis based on the revisions to the design options at each efficiency level. In addition, DOE updated raw material and purchased parts costs based on the latest available data, as well as updating costs for manufacturing equipment, labor, and depreciation. For product classes for which AHAM provided data, the corresponding cost-efficiency curves are plotted as well. The EF values (for both DOE and AHAM data) shown below are adjusted using the percentage increases to account for the amendments to the DOE clothes dryer test procedure (10 CFR part 430, subpart B, appendix D1), as discussed above in section 5.4.1.1.

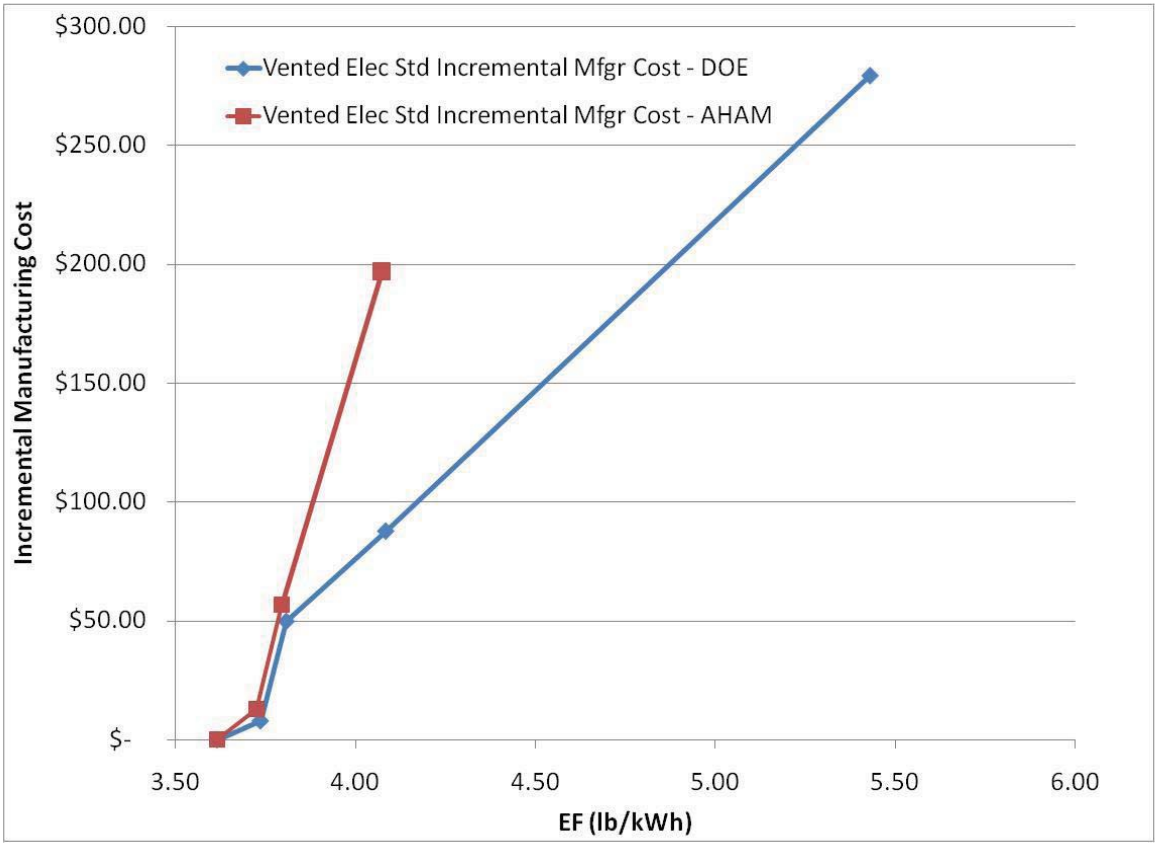


Figure 5.6.19 Vented Electric Standard Clothes Dryer Cost-Efficiency Curves

Table 5.6.9 Vented Electric Standard Clothes Dryer Incremental Manufacturing Costs

Efficiency Level (EF, *lb/kWh*)	**Incremental Cost**
Baseline (3.62)	$0
1 (3.74)	$7.92
2 (3.81)	$49.85
3 (4.08)	$87.79
4 (5.43)	$279.43

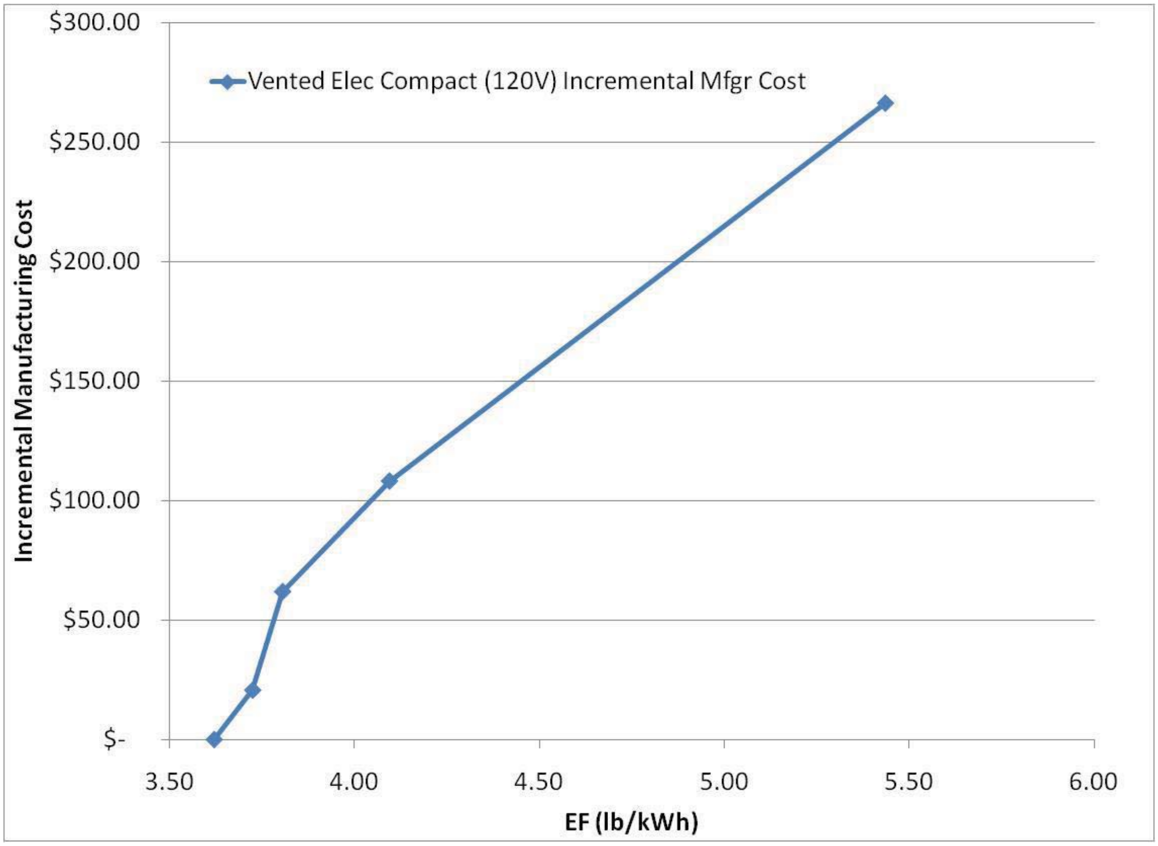


Figure 5.6.20 Vented Electric Compact (120V) Clothes Dryer Cost-Efficiency Curve

Table 5.6.10 Vented Electric Compact (120V) Clothes Dryer Incremental Manufacturing Costs

Efficiency Level (EF, *lb/kWh*)	Incremental Cost
Baseline (3.62)	$0
1 (3.72)	$20.64
2 (3.80)	$61.94
3 (4.09)	$108.21
4 (5.44)	$266.37

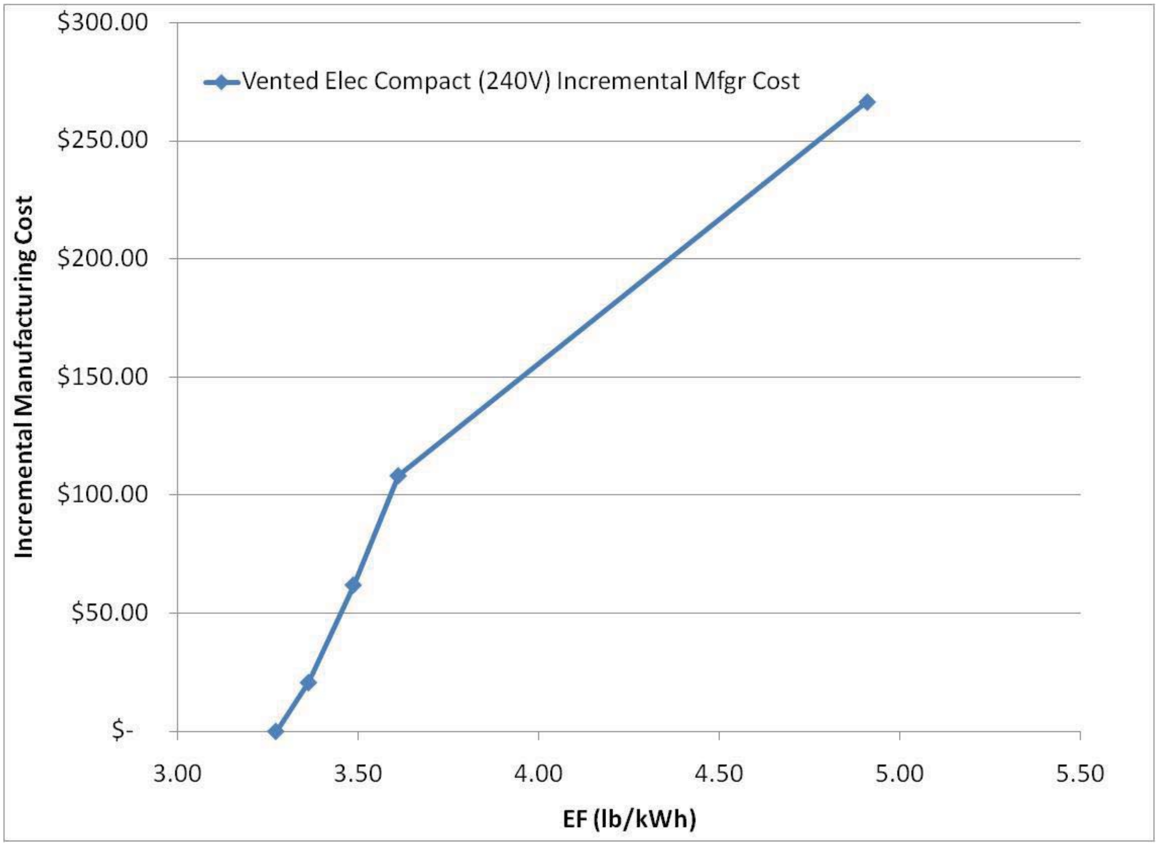


Figure 5.6.21 Vented Electric Compact (240V) Clothes Dryer Cost-Efficiency Curve

Table 5.6.11 Vented Electric Compact (240V) Clothes Dryer Incremental Manufacturing Cost

Efficiency Level (EF, *lb/kWh*)	**Incremental Cost**
Baseline (3.27)	$0
1 (3.36)	$20.64
2 (3.49)	$61.94
3 (3.61)	$108.21
4 (4.91)	$266.37

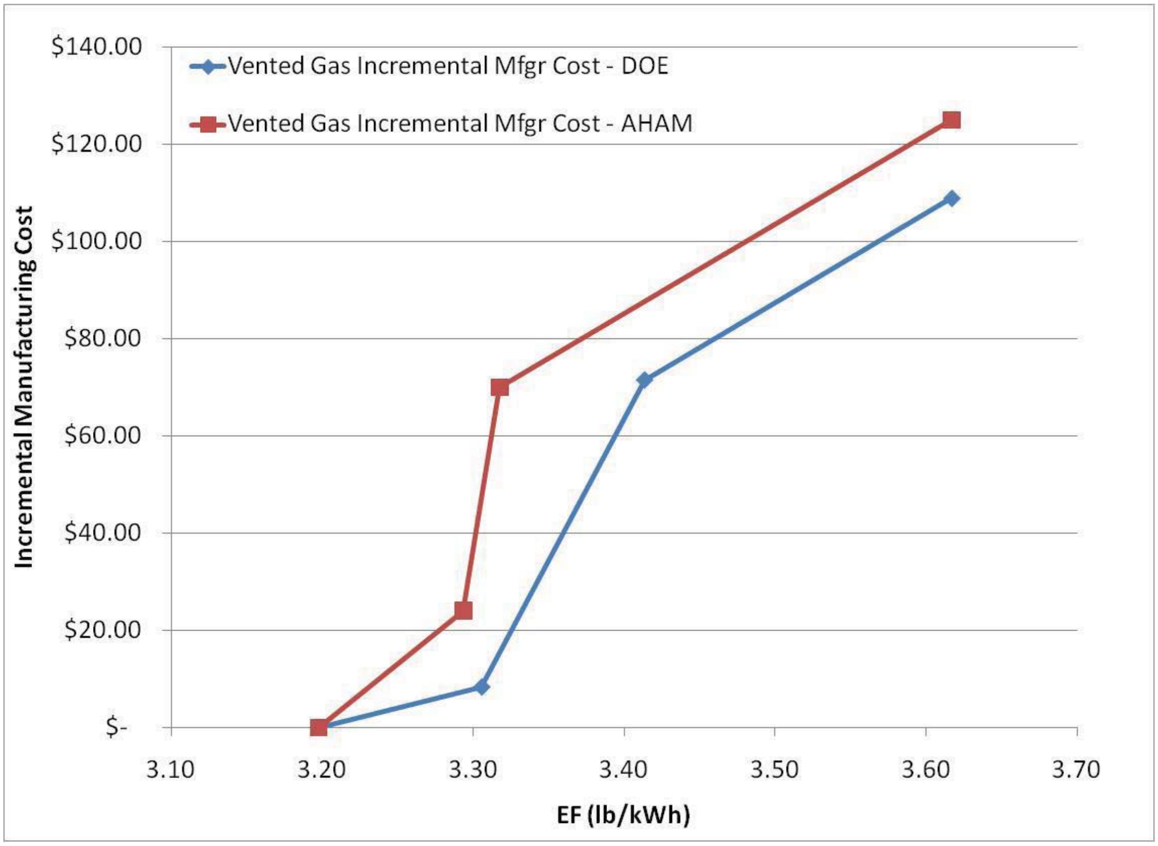


Figure 5.6.22 Vented Gas Clothes Dryer Cost-Efficiency Curves

Table 5.6.12 Vented Gas Clothes Dryer Incremental Manufacturing Cost

Efficiency Level (EF, *lb/kWh*)	**Incremental Cost**
Baseline (3.20)	$0
1 (3.31)	$8.30
2 (3.41)	$71.50
3 (3.62)	$108.87

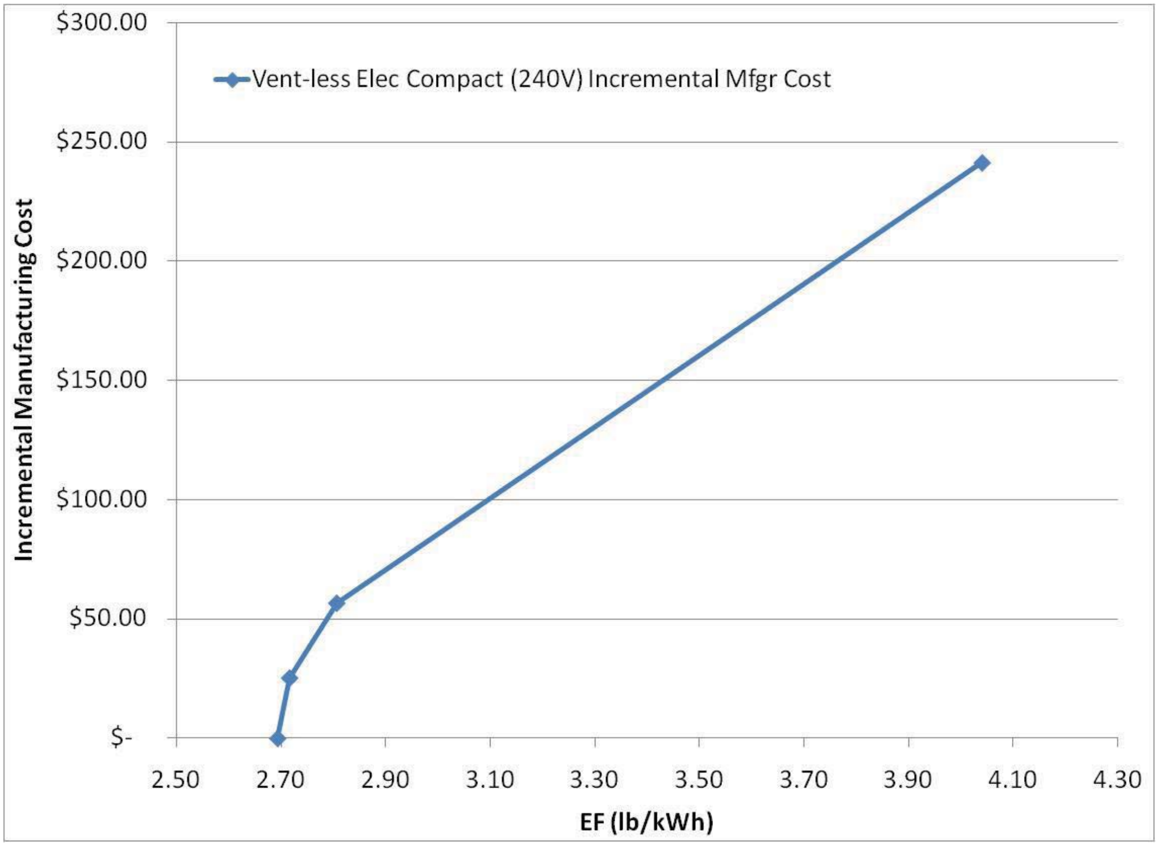


Figure 5.6.23 Ventless Electric Compact (240V) Clothes Dryer Cost-Efficiency Curve

Table 5.6.13 Ventless Electric Compact (240V) Clothes Dryer Incremental Manufacturing Cost

Efficiency Level (EF, *lb/kWh*)	**Incremental Cost**
Baseline (2.69)	$0
1 (2.72)	$25.31
2 (2.81)	$56.69
3 (4.04)	$241.25

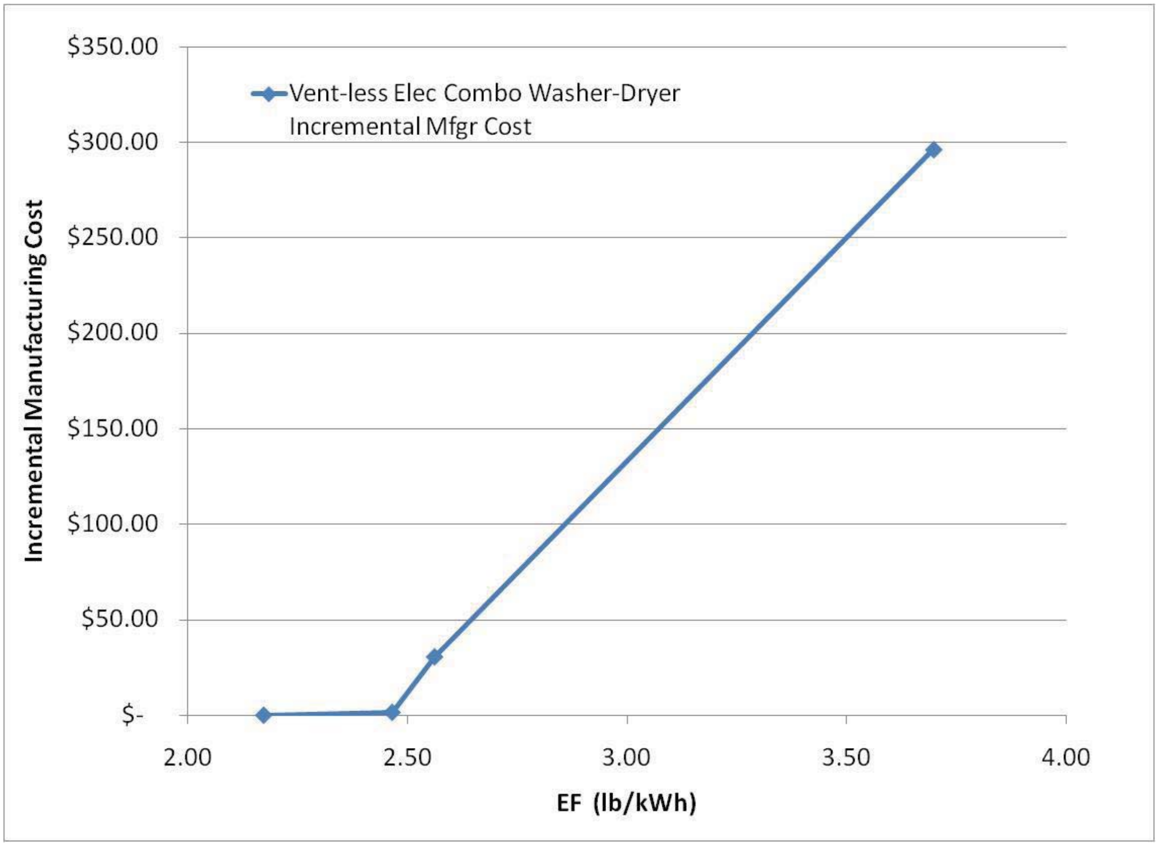


Figure 5.6.24 Ventless Electric Combination Washer/Dryer Cost-Efficiency Curves

Table 5.6.14 Ventless Electric Combination Washer/Dryer Incremental Manufacturing Cost

Efficiency Level (EF, *lb/kWh*)	**Incremental Cost**
Baseline (2.17)	$0
1 (2.46)	$1.51
2 (2.56)	$30.58
3 (3.70)	$296.43

Standby Mode

Based upon the product teardowns and cost modeling, DOE developed the incremental costs associated with decreasing standby power consumption, shown in Table 5.6.15. As discussed above for the active mode incremental manufacturing costs, DOE updated the incremental costs for standby power design changes based on the latest available electronics components pricing.

Table 5.6.15 Standby Power Incremental Manufacturing Cost

Standby Power Level *(W)*	Incremental Cost
Baseline (2.0)	$0
1 (1.5)	$0.93
2 (0.08)	$1.11

Incremental Costs by CEF

As discussed in section 5.4, the clothes dryer analysis for this rulemaking is based on the integrated metric, CEF. DOE analyzed the improvement in CEF associated both with design options that improve EF and design options that reduce standby power. DOE developed overall cost-efficiency relationships for the CEF efficiency levels presented in section 5.4.2.3. As noted above in section 5.4.2.3, DOE incorporated incremental standby power levels into CEF efficiency levels where DOE determined them to be most cost effective. In addition, as discussed above in section 5.4.2.3, DOE analyzed baseline efficiency products available on the market, and weighted the efficiency improvement and incremental manufacturing cost associated with standby power based on the percentage of baseline efficiency products that have electronic controls. For the integrated efficiency levels for which electronic controls would be required as part of the active mode design changes, DOE assumed that the standby power levels and incremental manufacturing costs affected 100 percent of clothes dryer models. Table 5.6.16 through Table 5.6.21 present DOE's estimates of incremental manufacturing cost for improvement of clothes dryer CEF above the baseline.

Table 5.6.16 Cost-Efficiency Relationship for Vented Electric Standard Clothes Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (3.55)	$0
1 (3.56)	$0.68
2 (3.61)	$0.82
3 (3.73)	$8.74
4 (3.81)	$50.67
5 (4.08)	$88.89
6 (5.42)	$280.54

Table 5.6.17 Cost-Efficiency Relationship for Vented Electric Compact (120V) Clothes Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (3.43)	$0
1 (3.48)	$0.68
2 (3.61)	$0.82
3 (3.72)	$21.46
4 (3.80)	$62.76
5 (4.08)	$109.31
6 (5.41)	$267.48

Table 5.6.18 Cost-Efficiency Relationship for Vented Electric Compact (240V) Clothes Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (3.12)	$0
1 (3.16)	$0.68
2 (3.27)	$0.82
3 (3.36)	$21.46
4 (3.48)	$62.76
5 (3.60)	$109.31
6 (4.89)	$267.48

Table 5.6.19 Cost-Efficiency Relationship for Vented Gas Clothes Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (3.14)	$0
1 (3.16)	$0.68
2 (3.20)	$0.82
3 (3.30)	$9.12
4 (3.41)	$72.32
5 (3.61)	$109.98

Table 5.6.20 Cost-Efficiency Relationship for Ventless Electric Compact (240V) Clothes Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (2.55)	$0
1 (2.59)	$0.93
2 (2.69)	$1.11
3 (2.71)	$26.42
4 (2.80)	$57.80
5 (4.03)	$242.36

Table 5.6.21 Cost-Efficiency Relationship for Ventless Electric Combination Washer/Dryers

Integrated Efficiency Level (CEF, *lb/kWh*)	Incremental Manufacturing Cost
Baseline (2.08)	$0
1 (2.35)	$1.51
2 (2.38)	$2.44
3 (2.46)	$2.62
4 (2.56)	$31.69
5 (3.69)	$297.54

5.6.1.5 Manufacturer Interviews – Preliminary Analysis

DOE conducted interviews with residential clothes dryer manufacturers to determine appropriate efficiency levels for the preliminary analysis and to develop a better understanding of the technologies used to improve energy efficiency. During these interviews, DOE asked manufacturers what max-tech efficiency levels would be appropriate for each clothes dryer product class. DOE also asked manufacturers what groupings of design options are used in baseline designs and what would be implemented to increase the energy efficiency in order to meet the efficiency levels proposed in section 0 for residential clothes dryers. The discussion helped DOE understand what proposed design options have already been implemented and what additional design options DOE should consider. In addition, DOE conducted discussions regarding issues with the DOE test procedure for clothes dryers. The discussion below represents a consolidation of the responses. DOE subsequently conducted another series of interviews with manufacturers to solicit feedback on preliminary manufacturing cost estimates DOE developed through the reverse engineering analysis.

Max-Tech Efficiency Levels

Manufacturers indicated that the current maximum-available EF for vented gas clothes dryers listed in the CEC product database is not achievable. Multiple manufacturers stated that the CEC product database has had errors in the values listed in the past for other products, and at least one manufacturer suggested that DOE test the maximum-available model to determine an appropriate max-tech level. As discussed in section 0, DOE tested the maximum-available gas clothes dryer and determined that it did not achieve the rated EF.

Multiple manufacturers indicated that an EF of approximately 3.0 would be an appropriate max-tech value. In addition, AHAM submitted incremental manufacturing cost data, aggregated from manufacturer inputs, for the max-tech active mode efficiency level for vented gas clothes dryers proposed in the framework document (3.02 EF).

Components That Influence Energy Efficiency

Manufacturers identified components that influence energy efficiency in residential clothes dryers that are related to baseline designs. DOE also identified components and design options that it believed could potentially influence energy efficiency in residential clothes dryers. DOE requested comment on each of these design options and their potential for increasing energy efficiency.

Manufacturers indicated that they use a single 4-pole induction motor to drive both the drum and the blower in their baseline clothes dryer. Manufacturers also use a single-element electric resistance heater for electric clothes dryers and a single-stage gas valve for gas clothes dryers. In addition, manufacturers generally incorporate electromechanical controls into their baseline units along with some form of automatic termination control by temperature sensing.

A number of manufacturers indicated that improvements to energy efficiency can be made by implementing more efficient fan motors in place of the standard 4-pole induction motor. Manufacturers believed that 1 to 5 percent improvement can be achieved using more efficient fan motors, such as electronically-commutated motors (ECM), however the costs are high.

Manufacturers also indicated that all of their units incorporate some form of automatic termination sensing control. Manufacturers stated that thermostatically controlled automatic termination control with electromechanical controls is generally the least accurate form of automatic termination sensing. Using moisture sensors along with the thermostat controlled automatic termination sensing can improve the accuracy of these systems. To increase the accuracy further, manufacturers indicated that they would use moisture sensing controls with thermistors, which give continuous feedback, along with electronic controls.

At least one manufacturer indicated that adding insulation could improve efficiency minimally. However, most manufacturers believed that there is no significant efficiency improvement with insulation.

A number of manufacturers indicated that modifying the air flow can improve efficiency. For example, multiple manufacturers indicated that switching the drum air flow design from front to back to a design flowing in through one side of the drum on the back and out through the other side of the back can improve efficiency 1 to 3 percent.

Manufacturers also indicated that preheating inlet air, either through the use of an air-to-air heat exchanger or recirculation of process air, can improve energy efficiency. Manufacturers indicated varying degrees of potential improvements to energy efficiency associated with this design option, ranging from 1 to 12 percent.

With regards to modulating heat, manufacturers indicated that they would incorporate a modulating heater to reach different efficiency levels. They also indicated that modulating gas valves are significantly more expensive than single-stage gas valves.

A number of manufacturers have indicated that they manufacture heat pump dryers for international markets. Most manufacturers stated that 30 to 50 percent efficiency improvement is possible using heat pump technology. Manufacturers indicated that they would generally consider using a R-134a compressor along with tube and fin heat exchangers.

Strategies to Increase Energy Efficiency

Manufacturers generally supported the proposed efficiency levels for the vented dryer product classes. However, a number of manufacturers indicated that the max-available gas efficiency level above 3.44 EF (proposed in the first set of preliminary manufacturer interviews) may be difficult to achieve. Manufacturers generally indicated that the max-available efficiency level for vented gas dryers should be between 3.0 and 3.06 EF (90 percent of the max-available level for vented electric standard). DOE subsequently adjusted the max-available gas dryer efficiency level based on updates to the CEC database. For the vented electric compact 120V product class, at least one manufacturer was in agreement with the method used to develop the efficiency levels. However, other manufacturers indicated that meeting even the baseline efficiency would be difficult.

For the ventless electric compact 240V product class, at least one manufacturer indicated that it believed the proposed efficiency levels were appropriate. However, a few manufacturers also indicated that the proposed efficiency levels were low compared to the efficiencies achieved by the units that they manufacture.

Although manufacturers cited different design pathways for meeting the proposed efficiency levels, in general they cited the following strategies to increase energy efficiency: (1) air flow system improvements, (2) modulating heat design, (3) inlet air preheating, (4) higher-efficiency motor designs, and (5) heat pump technology for electric dryers.

Manufacturers indicated that air flow system changes would be included in design changes to meet the proposed efficiency levels. Some manufacturers cited such changes as using direct duct heaters to provide better heating and minimize heat losses. Other manufacturers indicated that better air flow sealing or insulation could also be used to meet efficiency levels. Manufacturers generally indicated that air flow system changes would be incorporated as part of design changes to meet EL 1 or EL 2 for vented dryers.

Manufacturers cited modulating heat designs as a strategy to improve energy efficiency. Some manufacturers indicated that the costs for this design change would be 3 to 4 times higher for a gas dryer, which would require a modulating gas valve and additional controls, as compared to an electric dryer, which would use either a multi-element resistance heater or a single element with modulating current. Various manufacturers indicated that they would use modulating heat as part of the design changes to meet EL 1 through EL 3 for vented dryers. Manufacturers also indicated that when adopting a modulating heater, they would additionally implement improved moisture sensing and more complicated controls systems.

Manufacturers also indicated that preheating inlet air is important to consider for achieving efficiency improvements. Some manufacturers indicated that this could be achieved by partial recirculation of the process air through the burner or heater system for all or part of the cycle. Manufacturers indicated that if they were to recirculate the process air, they would add or modify lint screens to prevent lint migration into the heater system. Other manufacturers believed that inlet air could be pre-heated by using a heat exchanger. Manufacturers that commented they would incorporate this design option, believed that it would be used as part of the design changes to meet either EL 2 or EL 3 for vented dryers.

Manufacturers cited improved motor efficiency as a strategy for meeting the proposed efficiency levels. Most manufacturers that commented that they would incorporate improved motor efficiency stated that they would likely incorporate this into the design changes for EL 3. Manufacturers indicated that they would likely use a separate ECM motor for the fan.

Manufacturers indicated that heat pump technology would provide the largest improvement to efficiency. Most manufacturers indicated that 30 to 50 percent improvement in efficiency can be achieved with heat pump dryers. However, manufacturers that produce compact-size heat pump clothes dryers for international markets indicated that the very long cycle times would be a consumer utility issue for U.S. consumers as well as the much higher initial cost of the unit.

A few manufacturers indicated that they would need to incorporate heat pump technology to reach EL 3 for vented electric standard dryers, which would be a 13 percent improvement over the baseline EF. DOE notes that there are currently units available on the market which meet EL 3 which do not incorporate heat pump technology and DOE believes that using heat pump technology can improve the efficiency beyond this point to the proposed EL 4. DOE also notes that some manufacturers indicated design changes to meet EL 3 that did not include switching to a heat pump design.

Manufacturers also noted that a number of the above mentioned design changes would require improved control systems using moisture sensing and electronic controls.

Manufacturers indicated that for ventless electric compact (240V) dryers, they would apply the same design changes as were used for vented electric dryers. In addition, they would consider modifications to the heat exchanger as a potential source for improving energy efficiency.

With regards to the proposed standby power levels for clothes dryers, at least one manufacturer commented in agreement with the proposed design changes for decreasing standby power in clothes dryers. They indicated that both incorporating a switching power supply and a transformerless power supply with a Triac to control power through the transformer are reasonable approaches to achieving standby levels 1 (1.5W) and 2 (0.08W). Again at least one manufacturer agreed that the incremental manufacturing costs associated with standby levels 1 and 2 that DOE developed through its reverse engineering analysis are appropriate.

Incremental Manufacturing Cost

In the initial set of preliminary manufacturing interviews, DOE requested feedback on whether the aggregated costs submitted by AHAM were representative of the manufacturing costs developed by each manufacturer. Most manufacturers indicated that the aggregated costs submitted by AHAM were representative of their costs for each efficiency level.

After DOE conducted the first round of preliminary manufacturer interviews, DOE developed incremental manufacturing cost-efficiency curves based on manufacturer inputs and reverse engineering analysis. DOE subsequently requested feedback from manufacturers on these incremental manufacturing cost-efficiency curves in order to refine its analysis. Manufacturers indicated that although they were not always in agreement with the design changes used to meet each efficiency level, they were generally in agreement with the incremental manufacturing cost-efficiency curves, indicating that values developed by DOE were generally within 20 percent of the values submitted by these manufacturers. Manufacturers also provided indications of the appropriateness of component pricing estimates used in DOE's cost model. DOE used information learned during these discussions to revise its reverse engineering analysis and incremental manufacturing costs.

Test Procedure Issues

DOE requested comment on a number of issues regarding the DOE test procedure for clothes dryers. Manufacturers indicated that they have observed test to test variation from 0.03 to 0.1 EF points for a single unit tested multiple times. At least one manufacturer indicated that latest test cloth may have some problems, showing variations in measured EF as the test cloth is used for multiple test runs. A number of manufacturers also indicated that variation in results can be seen within the allowable range ambient humidity and temperatures. Manufacturers stated that variations in ambient humidity had more of an effect on results than temperature. However, at least one manufacturer indicated that the ambient conditions are difficult to maintain and it would be hard to justify tighter tolerances given the requirements of increased control.

5.6.1.6 Manufacturer Interviews – Final Rule

DOE conducted additional interviews with residential clothes dryer manufacturers to discuss the efficiency levels and incremental manufacturing costs proposed in the preliminary analysis and to develop a better understanding of the challenges that manufacturers face in order to improve energy efficiency. During these interviews, DOE asked manufacturers what groupings of design options are used in baseline designs and what would be implemented to increase the energy efficiency in order to meet higher efficiency levels for residential clothes dryers. DOE also asked manufacturers about repair and maintenance costs for residential clothes dryers at higher efficiencies, as well as the manufacturing costs associated with complying with the Underwriters Laboratory (UL) Standard 2158 "Electric Clothes Dryers" (UL 2158) fire containment requirements. In addition, DOE conducted discussions regarding issues with the DOE test procedure for clothes dryers. The discussion below represents a consolidation of the responses.

Strategies to Increase Energy Efficiency

Manufacturers generally supported the design changes and efficiency levels analyzed by DOE for the preliminary analysis. However, a number of manufacturers indicated that they would likely incorporate 2-stage modulating heat as part of the design changes to meet active mode EL2 for vented clothes dryer product classes, and that inlet-air preheating would be incorporated to the design changes used for active mode EL2 to achieve active mode EL3.

Manufacturers also indicated that inlet-air preheating would theoretically result in a 5 to 15 percent improvement in efficiency. Manufacturers noted that in real-world situations, the potential efficiency improvement would be limited the necessary fin spacing for heat exchangers to prevent lint fouling. In addition, manufacturers indicated that improvements in efficiency would be limited by issues with condensation

Repair and Maintenance Costs

DOE requested information on how repair and maintenance costs would be impacted by more stringent energy conservation standards. A number of manufacturers indicated that repair and maintenance costs and frequency of repairs would likely increase with increased complexity and number of parts. Manufacturers also indicated that heat pump technology would significantly increase time and cost of repair and maintenance due to the addition of more complex refrigeration systems.

Underwriters Laboratory Standard 2158 - Electric Clothes Dryers

DOE requested information from clothes dryer manufacturers on the manufacturing costs and design changes required to comply with the UL 2158 fire containment requirements. Manufacturers indicated that, among other changes, a number of plastic components would have to be changed to metal, in particular for airflow ducting. However, DOE did not receive sufficient data to determine the incremental manufacturing costs to baseline clothes dryers to comply with the fire containment requirements of UL 2158. In addition, DOE did not receive sufficient information to indicate that the cost associated with complying with UL 2158 would vary at efficiency levels above the baseline. As a result, DOE did not include additional cost to comply with UL 2158 in the baseline manufacturing production cost. As discussed in chapter 13 of this TSD, DOE has investigated the costs of complying with the fire containment requirements in UL 2158 in the cumulative regulatory burden for the manufacturer impact analysis (MIA).

Test Procedure Issues

DOE requested comment on a number of issues regarding the DOE test procedure for clothes dryers. Multiple manufacturers stated that if DOE were to change the 50 percent cotton/50 percent polyester mix test cloth to a 100 percent cotton test cloth would increase the test-to-test variation. Multiple manufacturers also indicated that increasing the clothes dryer load size would increase the measured efficiency.

With regards to test load preparation, a number of manufacturers indicated that changing the water temperature for clothes dryer test load preparation from 100 °F ± 5 °F to 60 °F ± 5 °F would be more representative of consumer usage. Manufacturers also stated that such a change would result in a reduction in the measured efficiency because of the additional energy required to heat the clothes load from a lower starting temperature.

5.6.2 Room Air Conditioners

DOE considered cost and efficiency information obtained from multiple sources for the room air conditioner engineering analysis. During the preliminary analysis, DOE conducted room air conditioner teardown assessments and developed a manufacturing cost model to calculate the manufacturing costs for designs of varying efficiency levels. The preliminary analysis reverse engineering work was primarily based on the HCFC-22 refrigerant products available at that time. During the final rule analysis, DOE supplemented this information with room air conditioner teardowns for selected products using R-410A refrigerant. DOE also carried out energy modeling supported by manufacturing cost analysis to determine the incremental cost associated with efficiency improvements for products using R-410A. DOE also conducted interviews with room air conditioner manufacturers to obtain greater insight into design strategies and their associated costs to improve efficiency. DOE conducted preliminary manufacturer interviews after the framework comment period. DOE also conducted additional manufacturer interviews after the preliminary analysis. DOE did not receive aggregated industry data from AHAM for the incremental costs to achieve higher efficiency levels, because too few manufacturers reported data to allow aggregation and reporting of the data.

5.6.2.1 AHAM Data

In support of the room air conditioner rulemaking, AHAM requested incremental manufacturing cost data from its member companies. As mentioned above, not enough responses were obtained to allow reporting to DOE. Table 5.6.22 and Table 5.6.23 describe market share by product class from 2005 to 2007. A large majority of the shipped products are from product classes 1 through 5, products without reverse cycle and with louvered sides.

Table 5.6.22 AHAM Room Air Conditioner Product Class Market Share Data Submittal: Product Classes 1 Through 5

	Without Reverse Cycle (RC) and With Louvered Sides (LS)				
Product Class	**1**	**2**	**3**	**4**	**5**
	<6k	**6–8k**	**8–14k**	**14–20k**	**>20k**
2005	37%	19%	30%	3%	2%
2006	23%	19%	34%	5.5%	3.9%
2007	32%	16%	36%	6%	2.6%

Table 5.6.23 AHAM Room Air Conditioner Product Class Market Share Data Submittal: Product Classes 6 through 16

	Without Reverse Cycle and Without Louvered Sides	With Reverse Cycle and With Louvered Sides		With Reverse Cycle and Without Louvered Sides		Casement Only	Casement Slider
		<20k	>20k	<14k	>14k		
Product Class	**6 - 10**	**11**	**13**	**12**	**14**	**15**	**16**
2005	7%	0.7%	0.1%	0.4%		0.4%	
2006	12%	1.0%		0.6%		0.6%	
2007	7%	**	**	**	**	0.4%	

**Insufficient responses were received by AHAM to allow reporting for these product classes.

Table 5.6.24 and Table 5.6.25 detail the shipment-weighted average energy efficiency of room air conditioner shipments from 2005 to 2007 by product class. AHAM did not provide data for product classes 6, 7, 10, 13, 14, and 15. The efficiency trends for presented in the tables are mixed, with EER increasing for some product classes and decreasing for others.

Table 5.6.24 AHAM Room Air Conditioner Shipment Weighted Efficiency Data (EER) Submittal: Product Classes 1 through 5

	Without Reverse Cycle (RC) and With Louvered Sides (LS)				
Product Class	**1**	**2**	**3**	**4**	**5**
	<6k	**6–8k**	**8–14k**	**14–20k**	**>20k**
2005	9.5	10.2	10.3	10.3	9
2006	9.8	10.4	10.4	10.5	9.2
2007	9.8	9.9	10.1	10.3	9.1

Table 5.6.25 AHAM Room Air Conditioner Shipment Weighted Efficiency Data (EER) Submittal: Product Classes 6 through 16

	Without Reverse Cycle and Without Louvered Sides		With Reverse Cycle and With Louvered Sides	With Reverse Cycle and Without Louvered Sides	Casement Slider
	8–14k	**14–20k**	**<20k**	**<14k**	
Product Class	**8**	**9**	**11**	**12**	**16**
2005	9.5	**	10.6	9.6	9.9
2006	9.5	**	10.5	9.6	**
2007	9.5	9.0	**		9.5

**Insufficient responses were received by AHAM to allow reporting for these product classes.

In addition to market share by product class and shipment-weighted average energy efficiency for room air conditioners, AHAM also submitted data disclosing market share by efficiency level and year. These data are tabulated in appendix 5B of this TSD.

5.6.2.2 Manufacturer Interviews

During the preliminary analysis in 2008, DOE conducted interviews with room air conditioner manufacturers to develop a better understanding of the technologies used to improve energy efficiency. These interviews took place as manufacturers were developing R-410A designs for 2010 but before ramp-up of manufacturing of these units. During these interviews, DOE asked manufacturers what groupings of design options would be required to increase the energy efficiency to meet the efficiency levels proposed in section 5.4.2 for room air conditioners. The discussions helped DOE understand which design options have already been implemented and which additional design options DOE should consider. The discussion below represents a consolidation of the responses.

DOE also conducted interviews with room air conditioner manufacturers during the final rule analysis, in 2010. These interviews took place after manufacturers' initial experience of full-line production of products using R-410A refrigerant. During these interviews, DOE asked manufacturers what groupings of design options are used in baseline designs and what would be implemented to increase the energy efficiency in order to meet higher efficiency levels for room air conditioners. DOE asked about the state of the R-410A transition and the technical challenges still facing manufacturers to meet higher efficiencies.

Components That Influence Energy Efficiency

Manufacturers identified the components that influence energy efficiency in room air conditioners as fans, blowers, fan motors, heat exchanger coils, and compressors. Most manufacturers use PSC fan motors. Some manufacturers have considered electronically-commutated motors (ECM), which use less energy than PSC fan motors, but generally have not pursued using them because of cost.

Manufacturers currently use rotary compressors in their room air conditioners, and the efficiency range of compressors available today varies by product class. Manufacturers were required to stop using HCFC-22 refrigerant starting in 2010, so manufacturers now use R-410A refrigerant. Compressor vendors were still developing their lines of R-410A compressors during the course of the analysis, so some of the information about them has been changing. Manufacturers mentioned during the preliminary analysis phase that the EER range for R-410A compressors currently available tops out at 10.0, as compared to 11.0 for HCFC-22 compressors. Manufacturers expected to be able to make up for much but not all of the difference as a result of the better heat transfer performance of R-410A. Manufacturers have not implemented variable-speed compressors because of the higher cost and because the steady conditions of the DOE test procedure do not capture the actual-use benefits of such compressors. Other compressor technologies, such as scroll or reciprocating compressors, are available only for higher capacity room air conditioners but are generally not used due to size, weight, and/or vibration issues.

Strategies to Increase Energy Efficiency

Manufacturers consider material cost, shipping cost, and weight as key design parameters. Manufacturers cited the following strategies to increase energy efficiency: (1) heat exchanger coil improvements or face area increase, (2) air system design improvement to increase air flow, (3) use of higher-efficiency fan motors, (4) higher-efficiency compressors, and (5) subcooler coils.

Manufacturers cited compressors as a key strategy to increase energy efficiency. However, as mentioned above, compressors vendors were not initially offering as full a range of compressor EER levels with R-410A compressors as have been available for HCFC-22. This is expected to change over the next few years, but initial R-410A designs were constrained by limitations in compressor availability.

Manufacturers are emphasizing heat exchanger coil improvements to increase energy efficiency, since this design option offers the most potential for improvement. Further increases in efficiency are typically only possible via increasing the coil area. Larger coils require more material, which manufacturers cited as a concern due to high material prices. Also, as coils grow, the chassis may have to grow as well. If the unit size and weight increase past a certain point, consumer utility is impacted. For larger capacity products, window sizes won't allow further size increases. Fewer products can fit in a shipping container, which results in higher per-unit shipping costs.

Manufacturers mentioned that maximizing air flow is also an important consideration in achieving efficiency improvements. This may involve reducing fin density or coil depth, using more powerful fans and/or blowers, and paying closer attention to minimizing losses in the air flow passages. However, more powerful fans can have a detrimental impact on consumer utility by making the room air conditioner noisier. Finally, while both higher efficiency PSC motors and subcooling coils were cited as having the potential to improve efficiency, the overall impact of these design options is relatively small.

Final Rule Analysis Interviews

Manufacturers in 2010 had experience with R-410A designs. However, because compressor vendors' product lines were not fully developed and because only one year of products had been produced, not all issues associated with the new refrigerant had been resolved.

All manufacturers stated that R-410A compressors were available, but choices were limited. Manufacturers reported that there were less compressor choices, in terms of efficiency and capacity. The maximum R-410A rotary compressor efficiency available for use in most products was still 10 EER, according to most manufacturers interviewed. However, testing and development of higher efficiency compressors was on-going.

The majority of manufacturers continued to concentrate on heat exchanger improvements, mainly through increases in product size. Some manufacturers reported limits in the potential size of heat exchangers, due to the impacts from excess refrigerant charge and possible impacts on dehumidification performance. Some manufacturers have had to increase the number of tube rows (*i.e.*, the depth) of the heat exchangers in their units. The increase of heat exchanger size often is accompanied by use of compressors with lower nominal capacity, because the operating capacity of the compressor increases when evaporating temperature is raised and condensing temperature lowered, as occurs with larger heat exchangers.

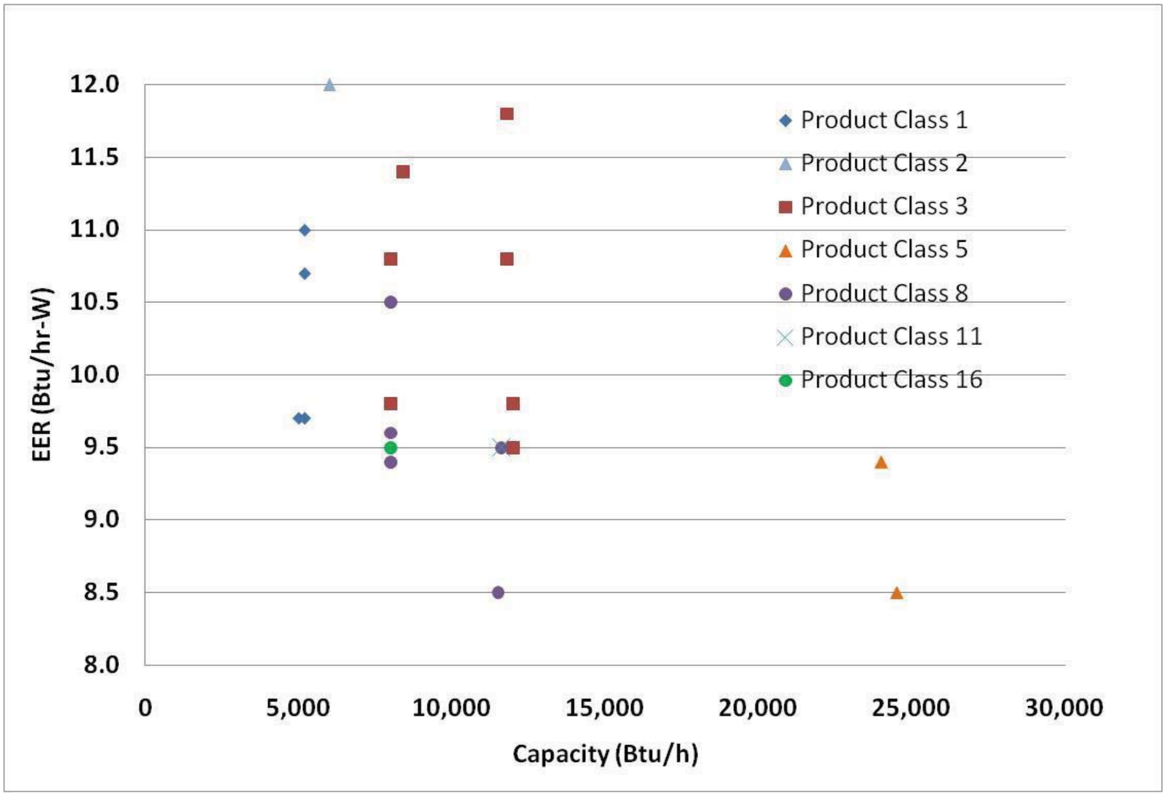
To implement new R-410A designs, some manufacturers reported that they had to grow their units to accommodate the larger heat exchangers, either by developing new product sizes or by using the next chassis size available (*e.g.*, using last year's 10,000 Btu/h product chassis for this year's 8,000 Btu/h product). All manufacturers are very sensitive to the cost of increasing the size of units, as larger sizes mean more material and more costs. Many times, the additional product costs have been borne by the manufacturers themselves, because the market is extremely competitive. However, manufacturers realize that they are reaching the limit of current box sizes.

Through-the-wall units (products with non-louvered sides) of higher capacity have faced an extreme challenge, because product size cannot be increased for these products. Some manufacturers reported that larger capacity products may be unable to meet efficiency standards, and may disappear from the market.

5.6.2.3 Product Teardowns

During the preliminary analysis, DOE conducted reverse engineering for 21 room air conditioners across 6 product classes to identify design options, and their associated costs, that can be used to raise EER. To the extent possible, DOE selected reverse engineering products of similar nominal capacity but varying efficiencies. Figure 5.6.25 shows the efficiency ranges of the selected products. The efficiency ranges for the products selected from product classes 1, 3, and 5 cover the range of efficiency levels of available products. For product classes 3 and 8, products were selected at capacity levels of both 8,000 Btu/h and 12,000 Btu/h.

DOE notes that all the room air conditioners torn down in the preliminary analysis used HCFC-22 as their refrigerant. DOE identified only one commercially available R-410A room air conditioner when this analysis was conducted. DOE purchased this unit and conducted reverse engineering, but did not conduct a full teardown of this unit. Nevertheless, DOE was able to obtain sufficient information about this unit to allow development of both an energy model and manufacturing cost model for it. The reverse engineering included close examination of all heat exchanger details, identification of the compressor and fan motor model number, and measurement of fan power input, among other things.



Note: The product class 2 unit did not undergo full teardown and uses R-410A refrigerant. All other products use HCFC-22 refrigerant. The 12,000 Btu/h 9.5 EER product class 3 product was advertised as being a through-the-wall product (product class 8).

Figure 5.6.25 Efficiency Range of Room Air Conditioner Teardowns

During the final rule phase, DOE conducted teardown analysis of commercialized R-410A products. This allowed confirmation and validation of information developed in the preliminary analysis. DOE tore down four R-410A room air conditioners, listed in Table 5.6.26.

Table 5.6.26 R-410A Teardown Products selected for validation of analysis

Teardown Unit	Product Class	Capacity (*Btu/hr*)	EER
1	1	5000	9.7
2	2	6,000	12.0
3	3	12,000	10.8
4	5B	28,500	8.5

During teardown analysis, DOE groups costs into key materials categories. Figure 5.6.26 shows the breakdown of material costs for a typical HCFC-22 baseline product class 3 room air conditioner, as generated from DOE's BOM, developed during the preliminary analysis. Note that the refrigeration system, heat exchangers, and fan components (components that largely determine energy consumption) make up 63 percent of the material costs. Figure 5.6.27 shows the various costs comprising a typical baseline product class 3 room air conditioner's full production cost. Depending on the manufacturer and the production volume, the depreciation costs may vary from those shown in the figure, which assumes a "green-field" site. Figure 5.6.28 and Figure 5.6.29 show the same breakdown for an R-410A ENERGY-STAR product class 3 room air conditioner. Note that the refrigeration system, heat exchangers, and fan components make up 73 percent of the material costs for this product.

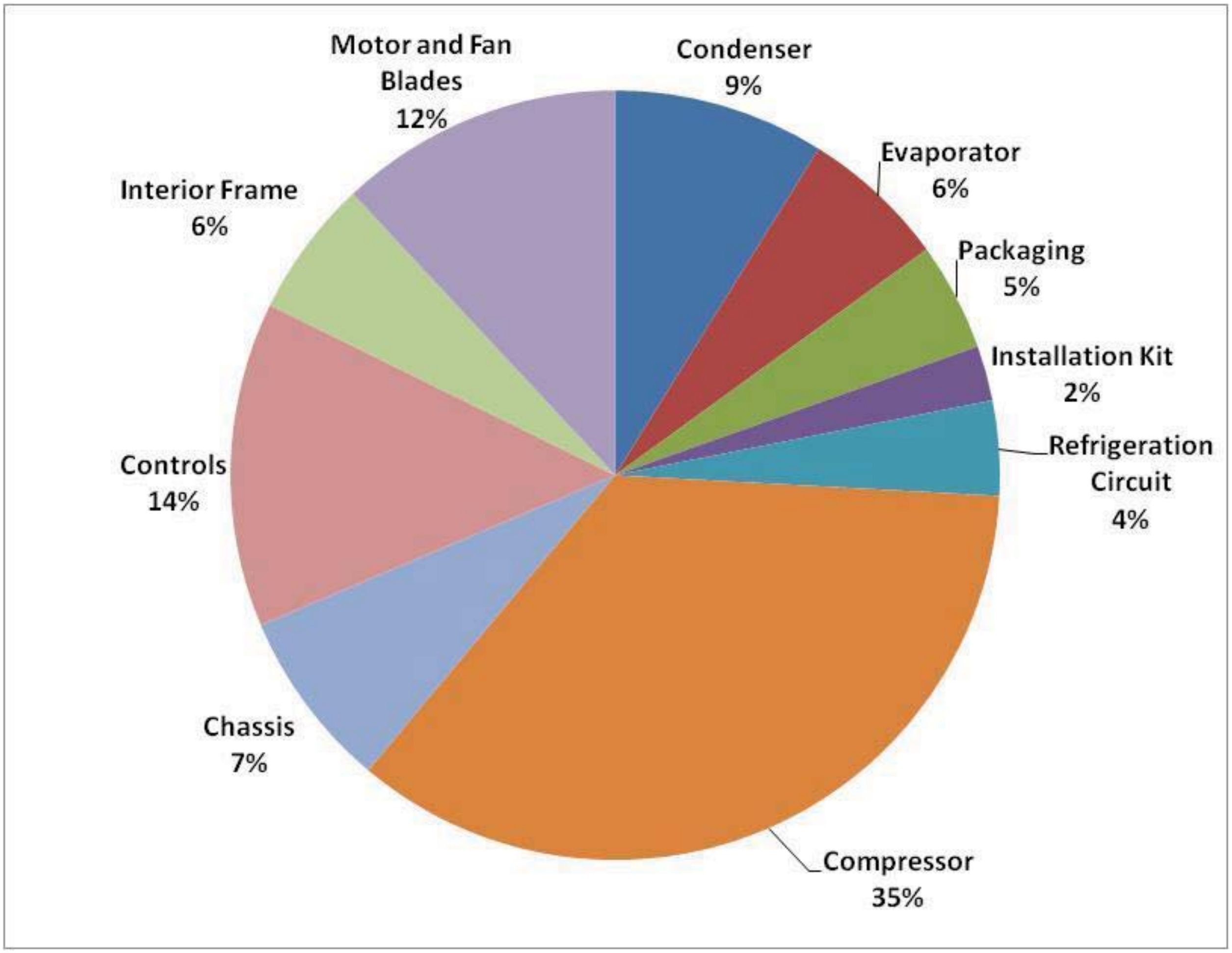


Figure 5.6.26 Baseline HCFC-22 Product Class 3 (12,000 Btu/h) Room Air Conditioner Material Cost Distribution ($157 total)

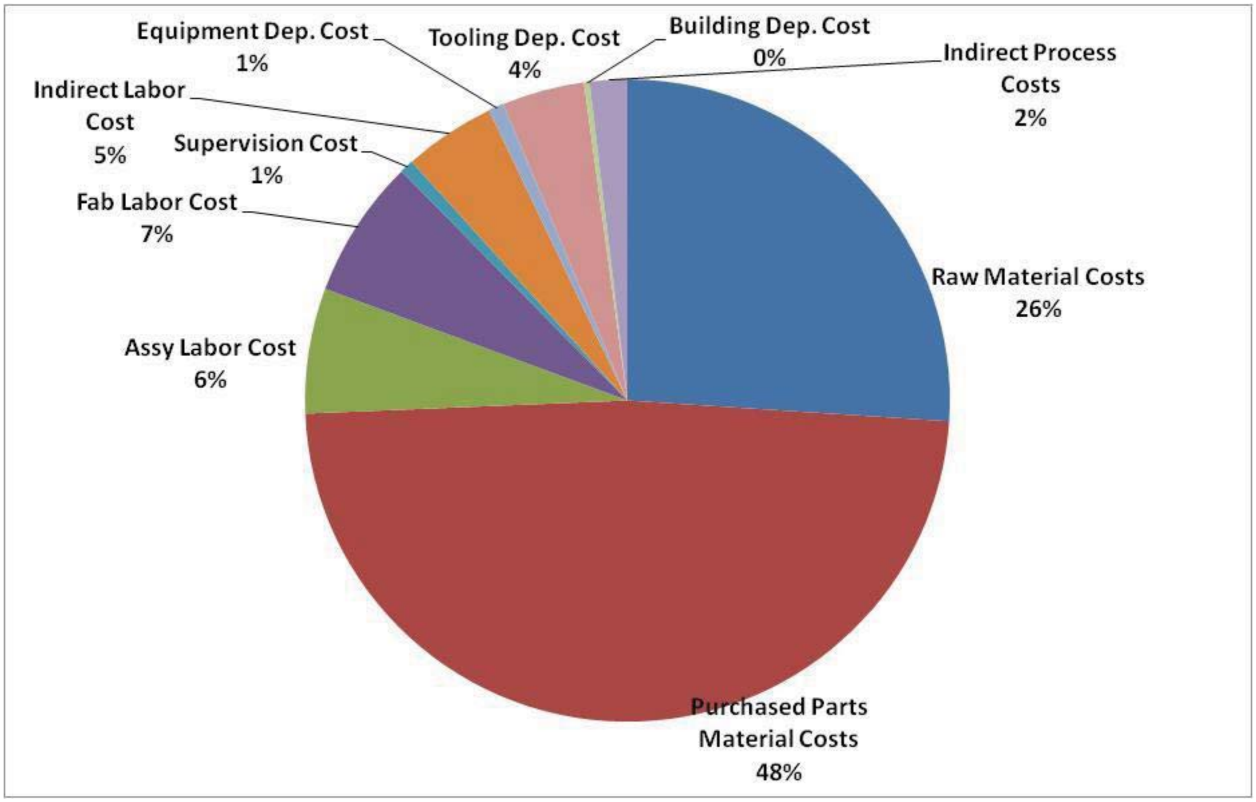


Figure 5.6.27 Baseline HCFC-22 Product Class 3 12,000 Btu/h Room Air Conditioner Full Production Cost Distribution ($195 total)

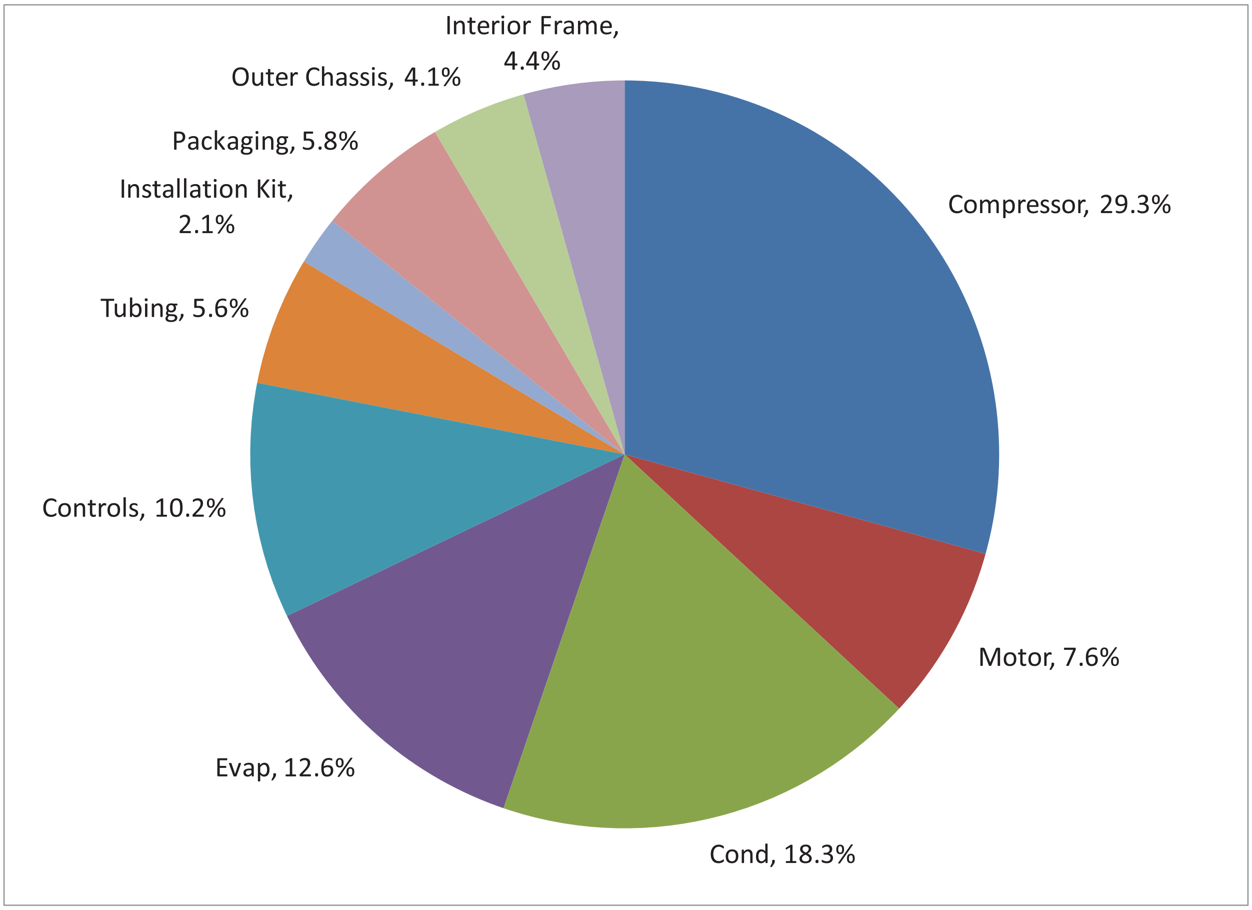


Figure 5.6.28 ENERGY-STAR R-410A Product Class 3 (12,000 Btu/h) Room Air Conditioner Material Cost Distribution ($150 total)

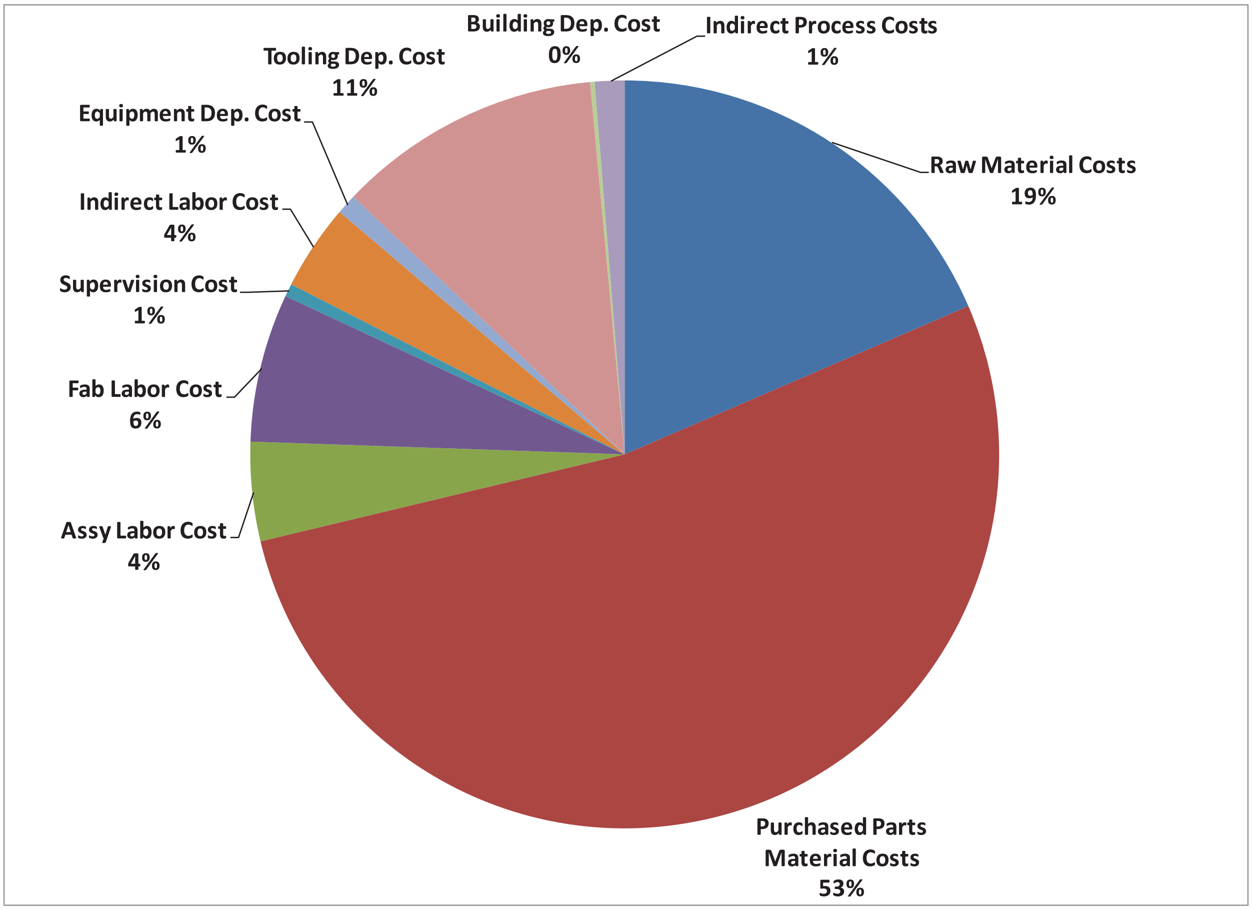


Figure 5.6.29 ENERGY-STAR R-410A Product Class 3 12,000 Btu/h Room Air Conditioner Full Production Cost Distribution ($211 total)

The manufacturing cost model was used in subsequent analysis to determine the cost of room air conditioner designs incorporating series of design options to increase efficiency. The results of these analyses are discussed in section 5.6.2.9.

Teardown of Max-Tech 6,000 Btu/h Units

During the preliminary analysis public meeting, General Electric (GE) noted that the 6000 Btu/h, 12.0 EER R-410A product DOE had identified during its preliminary analysis had been mentioned in a Consumer Reports article indicating that a sample tested by Consumer Union did not meet the 12.0 EER rating[g]. GE recommend that DOE should consider another heavier 6,000 Btu/h, 12.0 EER R-410A unit as more representative for its analysis. A comparison of these two units is presented in Table 5.6.27.

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[g] Consumer Reports. October 2008. Pg. 24 Vol. 73 No. 10. Copyright 2008 Consumers Union of U.S., Inc.

Table 5.6.27 R-410A Characteristics of Selected R-410A 6,000 Btu/h 12.0 EER Units

Brand	Haier	Friedrich
Model	ESA4066	XQ06M10
Product Dimensions (W×H×D)	13.63” × 19.75” × 17.75”	14” × 19.75” × 21.38”
Product Volume (*cubic feet*)	2.75	3.5
Weight (*lb*)	57	72

DOE considered the Consumer Reports article regarding this product, which was initially considered to represent 12.0 EER using R-410A. Matching this performance level with the energy model required making some input assumptions at the optimistic end of reasonable expectations, particularly for the condenser air flow rate. Given the information now available, DOE has revised its analysis, using the Friedrich 12.0 EER product to represent the highest-efficiency available for low-capacity room air conditioners with louvered sides. The revised analysis for product class 1 is based on calibration of the energy model to match the performance of the Friedrich product. DOE conducted a teardown of this product to verify its design details. The Friedrich unit has a capacity of 6,000 Btu/h, just above the capacity range for product class 1. Section 5.6.2.7 describes the adjustments to the product class 1 engineering analysis in greater detail.

DOE conducted energy modeling in order to determine what design options are required to achieve increased efficiency levels in room air conditioners using R-410A refrigerant. DOE upgraded the energy model developed as part of the previous room air conditioner energy conservation standard rulemaking for this purpose. The original room air conditioner energy model was an adaptation of the Oak Ridge National Laboratory Mark III Heat Pump program for modeling of room air conditioner cooling performance and is described in the 1997 TSD from the previous room air conditioner energy conservation standards rulemaking.[5] Additional modifications made during this rulemaking to upgrade the program for modern room air conditioners include the following.

- Revision of the heat exchanger performance models to reflect more recent correlations for airside heat transfer and pressure drop performance. This includes correlations for the slit fins typically used in today’s room air conditioners as well as for microchannel heat exchangers.
- Incorporation of property routines for other refrigerants, including R-410A.
- Development of a platform to allow running the program in the Microsoft Windows operating system.

The modified program is called MarkN. Because MarkN does not incorporate calculation of the performance of fans or blowers or the air pressure drops associated with components other than the heat exchangers, DOE conducted some modeling external to the program to properly account for system changes that impact air flows. DOE developed airside models that calculated the pressure losses within the room air conditioner of air passages, flow transitions, inlets, and outlets, and that incorporated heat exchanger pressure drop results from MarkN for both the evaporator and condenser. The airside models also included models of the fan or blower performance. With the airside model used in conjunction with MarkN, DOE was able to properly account for the impacts on air flow and fan motor shaft power associated with the analyzed design modifications.

Fan performance information was generally not available for the fans and blowers of the teardown models that were analyzed. DOE obtained performance data for similar fans and blowers from vendors. DOE adjusted the available fan and blower performance information using the fan laws from the 2008 ASHRAE Handbook, HVAC Systems and Equipment[6], to approximate the performance of the components in the products that were analyzed. Further information on the airside models is available in appendix 5D of this TSD.

DOE modeled the energy use for each of the teardown units and compared to the rated performance for these units to verify the validity of the upgraded energy model. DOE based inputs for the individual models on the design details determined during teardown of the products. DOE determined some of the system operating parameters using energy testing, as discussed in section 5.6.2.4. DOE set evaporator air flow equal to the rated evaporator air flow. DOE also made hot wire anemometer measurements of condenser air flow and fan motor power input measurements prior to teardown to provide model input for these parameters. DOE used data obtained from compressor vendors to represent compressor performance.

Comparisons of energy model results and rated performance of the teardown units are shown in Figure 5.6.30 below. The figure shows that both capacity and efficiency of the products were well predicted by the energy model. Of these products, only the 6,000 Btu/h 12.0 EER room air conditioner used R-410A refrigerant. All other units used HCFC-22 refrigerant.

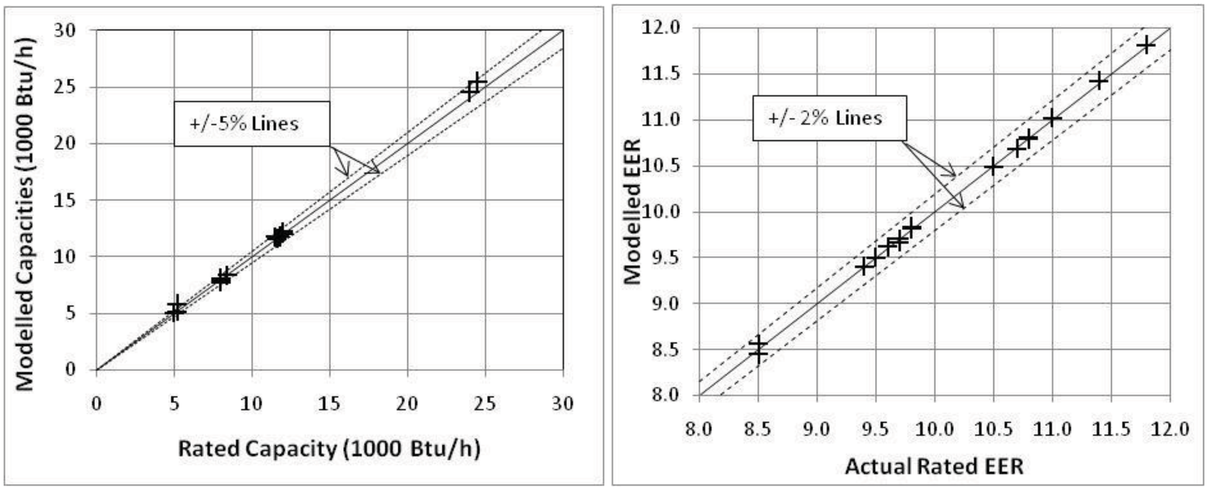


Figure 5.6.30 Comparison of Energy Modeling Results with Rated Air Conditioner Performance

After calibration of the energy models by comparison with rated performance data as discussed above, DOE used the energy model to determine the energy impact of conversion to R-410A refrigerant. DOE conducted this analysis for all of the teardown products using HCFC-22 refrigerant, assuming only drop-in of an R-410A compressor with no other adjustments for the new refrigerant. DOE obtained performance data of the R-410A compressors from compressor vendors. The R-410A drop-in analyses are compared with the baseline HCFC-22 analyses in Figure 5.6.31 below. The models generally show a reduction in EER in the range of 0 to 15 percent.

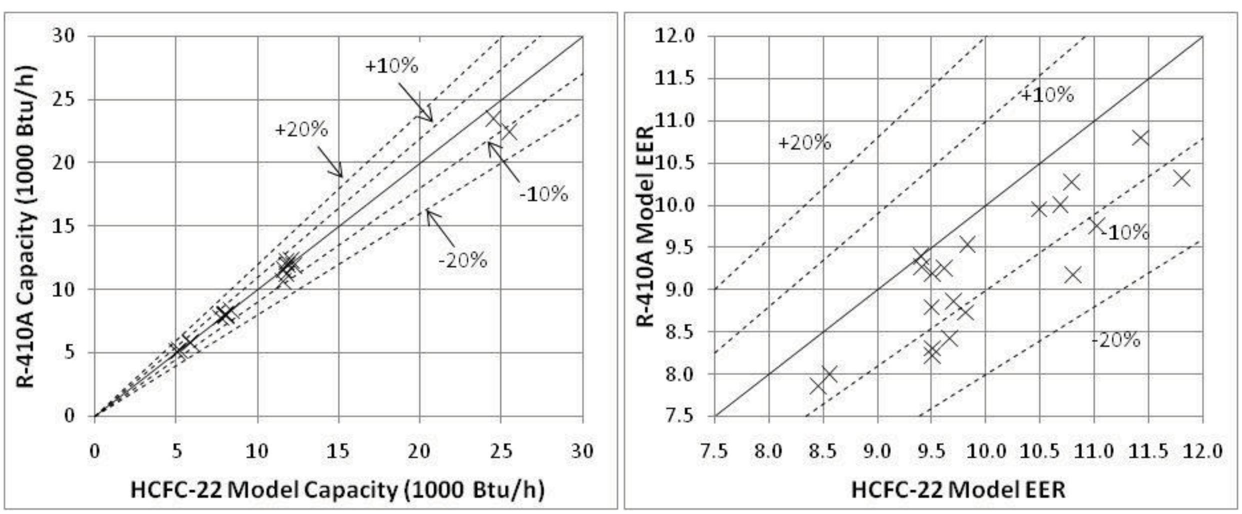
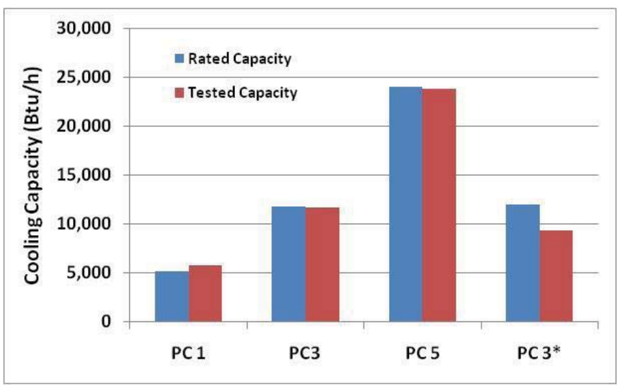


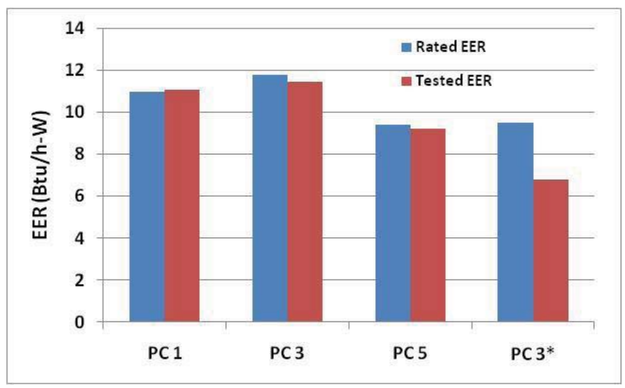
Figure 5.6.31 Energy Modeling Results for R-410A Drop-In

DOE conducted further energy analysis on designs modified by a series of design options in order to determine the energy efficiency improvement possible with each of these design options. For the final rule analysis, DOE performed this analysis for the seven baseline-efficiency products of product classes 1, 3, 5A, 5B, 8A, and 8B (DOE conducted analysis for product class 3 designs at 8,000 Btu/h and 12,000 Btu/h capacities). For all of these products, some improvement was required for the initial R-410A design in order to achieve EER levels meeting the current DOE energy standards. Additional improvements allowed examination of the incremental cost for efficiency improvements for R-410A room air conditioners. The results of the design option energy modeling analyses are discussed in section 5.6.2.9 below.

5.6.2.4 Energy Testing

During the preliminary analysis, DOE tested four units prior to teardown. DOE used the energy test results to verify performance of some of the higher-efficiency products. The comparison between rated and tested performance is shown in Figure 5.6.32 below. Test results for three of the units were close to the rated performance, while the results of the fourth were not.





*This product was advertised as being for through-the-wall installations (*i.e.* product class 8), but it had louvered sides.

Figure 5.6.32 Room Air Conditioner Energy Test Results

The energy testing conducted with additional instrumentation to allow recording of system temperatures. These measurements were used during energy modeling to help in calibration of the models with test results. Refrigerant temperatures were approximated by measurement of tube surface temperatures with thermocouples adhered to the tubes and externally insulated. The additional system measurements included:

- compressor discharge;
- condenser mid (a return bend roughly halfway between the condenser inlet and outlet, a location where the refrigerant is expected to be at saturated conditions);
- condenser outlet or subcooler outlet (for those units having a subcooler);
- evaporator inlet;
- evaporator outlet; and
- suction.

5.6.2.5 R-410A Conversion Costs

DOE determined, from manufacturer and vendor interviews, that there were intrinsic costs associated with the conversion from HFC-22 to R-410A. From these interviews, DOE determined that these cost increases include increased compressor costs, increased costs of the switch to polyolester (POE) oil, and increased refrigerant cost. DOE considered the impacts of each effect when calculating the cost of manufacturing for each room air conditioner.

Compressor Costs

From interviews with manufacturers and compressor vendors, DOE determined that rotary compressors designed for use with R-410A carried a higher price than compressors for HCFC-22 refrigerant. R-410A compressors require a thicker shell due to the higher pressures of R-410A, which is a key factor in the cost increase. Using the feedback from a variety of interviews, DOE used a compressor cost premium of 10 percent for R-410A compressors. This cost is for an R-410A compressor matching the capacity of the R-22 compressor it replaces.

Compressor Oil Switch

Due to miscibility issues, HFC refrigerants generally cannot be used in compressors lubricated with mineral oils, which have been used with HCFC-22. POE oils are being used in R-410A rotary compressors. DOE calculated the additional cost of oil based on the price difference between mineral oil and POE oils. The cost of the compressor oil switch was added separately, because the 10 percent compressor cost increase mentioned above is based on purchasing compressors without oil. The prices of mineral oil and POE oil were based on manufacturer and oil vendor inputs.

Refrigerant Switch

During interviews, manufacturers mentioned that R-410A costs more than HFC-22. DOE calculated the cost increase associated with the refrigerant based on the HCFC-22 charge of the teardown units. The costs of R-410A and HFC-22 refrigerants were based on inputs from manufacturers and retail sources of refrigerant.

DOE added the impacts of these three factors to calculate the total cost increase of the R-410 drop-in conversion. Table 5.6.28 below summarizes these costs for each analyzed product class. Note that the designs associated with these costs have lower EER than the baseline, and hence additional costs need to be added to represent the cost increase to maintain the baseline efficiency with an R-410A product. These additional costs were determined as the first step in the analysis of design options for improvement of efficiency, and they are discussed in section 5.6.2.5.

Table 5.6.28 Manufacturing Cost Increase for Drop-In Conversion to R-410A

Product Class	Total Costs Due to Refrigerant Switch
1 (5,000 Btu/h Capacity)	$3.29
3 (8,000 Btu/h Capacity)	$4.48
3 (12,000 Btu/h Capacity)	$6.27
5 (24,000 Btu/h Capacity)	$11.43
5B (28,000 Btu/h Capacity)	$ 11.43
8A (8,000 Btu/h Capacity)	$4.78
8B (12,000 Btu/h Capacity)	$6.73

5.6.2.6 Analysis Treatment of Design Options

To generate cost-efficiency curves, DOE examined both design options that influence EER and design options that influence standby or off mode energy use.

After the screening analysis and further elimination of design options discussed in section 5.2.2, DOE retained the design options listed in Table 5.6.29 below for improvement of efficiency.

Table 5.6.29 Retained Design Options for Room Air Conditioners

Increased Heat Transfer Surface Area
1. Increased frontal coil area
2. Increased depth of coil (add tube rows)
3. Increased fin density
4. Add subcooler to condenser coil
Increased Heat Transfer Coefficients
5. Microchannel heat exchangers
Component Improvements
6. Improved blower/fan motor efficiency
7. Improved compressor efficiency
Standby Power Improvements
8. Switching Power Supply

DOE determined the energy savings associated with each of these design options using energy modeling. DOE determined the cost impact per option using the manufacturing cost model established during the teardown analysis, obtaining additional input on component costs from vendor inquiries and manufacturer interviews. Details regarding the approach to savings and cost calculations for each of the design options are discussed below in greater detail.

Increased Frontal Coil Area

The energy and manufacturing cost models directly calculate the benefit and cost of increasing frontal coil area. DOE considered a number of variants on this design option, depending on the details of the baseline product under consideration.

Increases in Evaporator Width

In some of the baseline products, the evaporator width was limited unnecessarily by placement of the electronic control board next to the evaporator, preventing its expansion along the face of the unit. In many cases, there was sufficient space in alternative locations for the controls, such as above the evaporator adjacent to the vent. One variant of this design option that DOE examined was placing the controls above the evaporator, rather than beside it, thus freeing space to expand the evaporator. Some teardown units already incorporated the placement of the controls above the evaporator, especially the high-efficiency units. It did not appear to have an impact on utility.

Bending of the Condenser Coil

For some products, it may be possible to add a bend to the condenser coil in order to fit more coil frontal area within an existing chassis size. DOE examined this approach for the product class 1 unit and for both product class 8 units (products without louvered sides). DOE observed that some of the teardown units had bent condensers.

Increasing Physical Size of Product

DOE believes that larger coil frontal area (and larger package size to allow it) are key factors in maximizing EER in the max-tech products of product classes 1, 3, and 5 (products with louvered sides). The sizes and weights of these units are shown in Table 5.6.30 below. This table includes both the HCFC-22 units of the preliminary analysis, and the R-410A teardown units of the final rule analysis. Each analyzed product class group (1, 3, 5A, 5B) contains a baseline efficiency product that was analyzed, all but product class 5B contains an ENERGY-STAR rated unit, and analyzed product classes 1 and 3 contain max-tech units. Product class 2 was included because DOE tore down the max-tech 6,000 Btu/h 12 EER unit.

Table 5.6.30 Sizes and Weights of Product Class 1, 3, 5A, and 5B Teardown Units

Design Description	Refrigerant	Width *(in)*	Height *(in)*	Depth *(in)*	Weight *(lb)*
Product Class 1					
Baseline 1, 9.7 EER	HCFC-22	15.5	11.75	12	38.6
Baseline 2, 9.7 EER	HCFC-22	17.28	11.16	7.28	36.5
Baseline 3, 9.7 EER	R-410A	17.28	12.84	11.16	38
10.7 EER	HCFC-22	18.91	12.46	14.69	48.2
11 EER*	HCFC-22	18.5	12.5	14	44.4
Product Class 2, 6,000 Btu/h					
12.0 EER*	R-410A	19.75	14	20.25	72
Product Class 3, 8,000 Btu/h					
Baseline, 9.8 EER	HCFC-22	18.5	12.5	15.5	49.4
10.8 EER	HCFC-22	18.59	12.75	16.34	49.4
11.4 EER	HCFC-22	25.94	15.94	27.38	108
Product Class 3, 12,000 Btu/h					
Baseline, 9.8 EER	HCFC-22	19.58	13.75	19.63	73
10.8 EER	HCFC-22	23.63	15	22.25	78.6
11.8 EER*	HCFC-22	25.94	22.25	27.38	108.8
10.8 EER	R-410A	19	14.5	21.25	67
Product Class 5A, 24,000 Btu/h					
Baseline, 8.5 EER	HCFC-22	26	17.69	28.41	132
9.4 EER	HCFC-22	26.5	18.63	25	135.2
Product Class 5B, 28,500 Btu/h					
Baseline, 8.5 EER	R-410A	26.5	18.75	25.5	138

* Max-tech Unit

In the preliminary analysis, DOE considered increase of the physical size of the room air conditioner for product classes 1, 3, and 5. For product class 8, size increase was not considered—since much of the market for room air conditioners without louvered sides involves installation in existing wall sleeves, size increase for product classes 6 through 10 (including 8) (products without reverse cycle without louvered sides), 12, and 14 (products with reverse cycle without louvered sides) are not possible. The sizes of the product class 1, 3, and 5 that DOE used to represent baseline and higher efficiency products in DOE's preliminary analysis are compared in Figure 5.6.33 with a distribution of product sizes of baseline-efficiency room air conditioners from the database developed by DOE from the CEC, ENERGY STAR, and AHAM databases described in chapter 3. The comparisons show that the sizes of the analyzed products could be increased without exceeding the size of other current baseline-efficiency products. DOE drew a similar conclusion when comparing weights of the analyzed product designs with the weights of other baseline products in the database. With an overall unit size increase, the frontal areas of both the evaporator and condenser can be increased. The sizes DOE used in the analysis are summarized in Table 5.6.33 below.

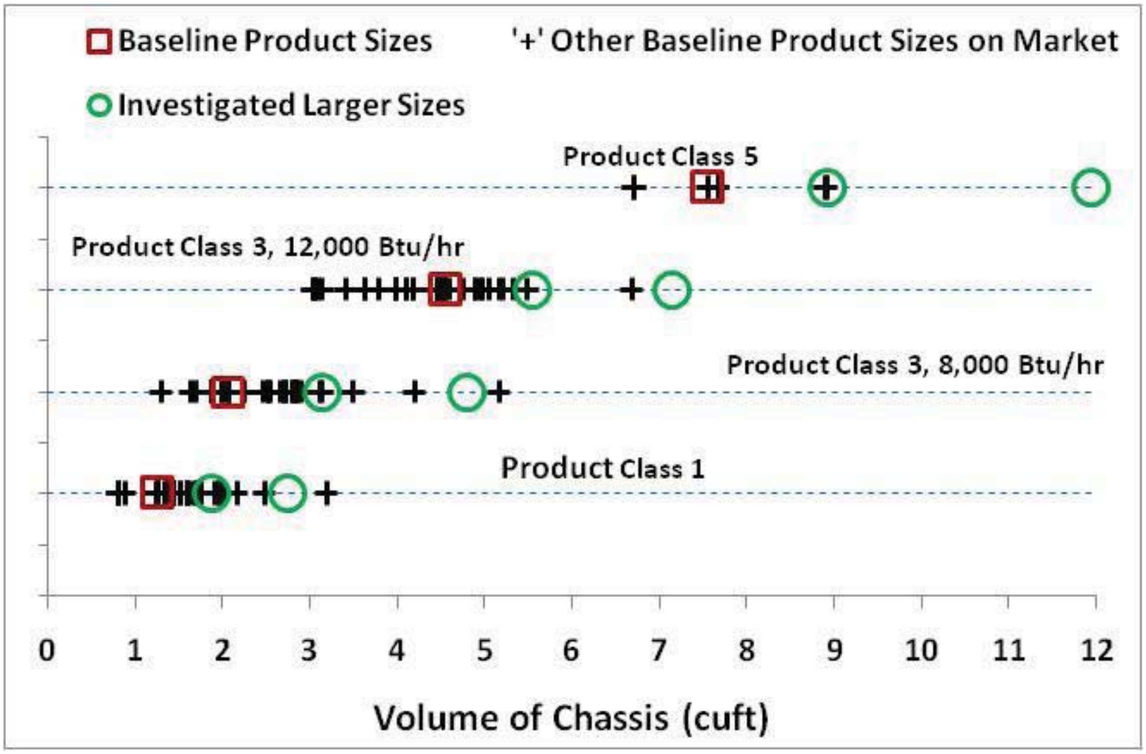


Figure 5.6.33 Size Distributions of Baseline-Efficiency Room Air Conditioners – HCFC Products on the Market

During the final rule analysis, DOE again compared the preliminary analysis product sizes against products on the market, in this case R-410A units. The results are shown in Figure 5.6.34 below. This assessment shows that the distribution of sizes of commercially available HCFC-22 room air conditioners examined during the preliminary analysis did not differ significantly from the size distribution of currently available R-410A products.

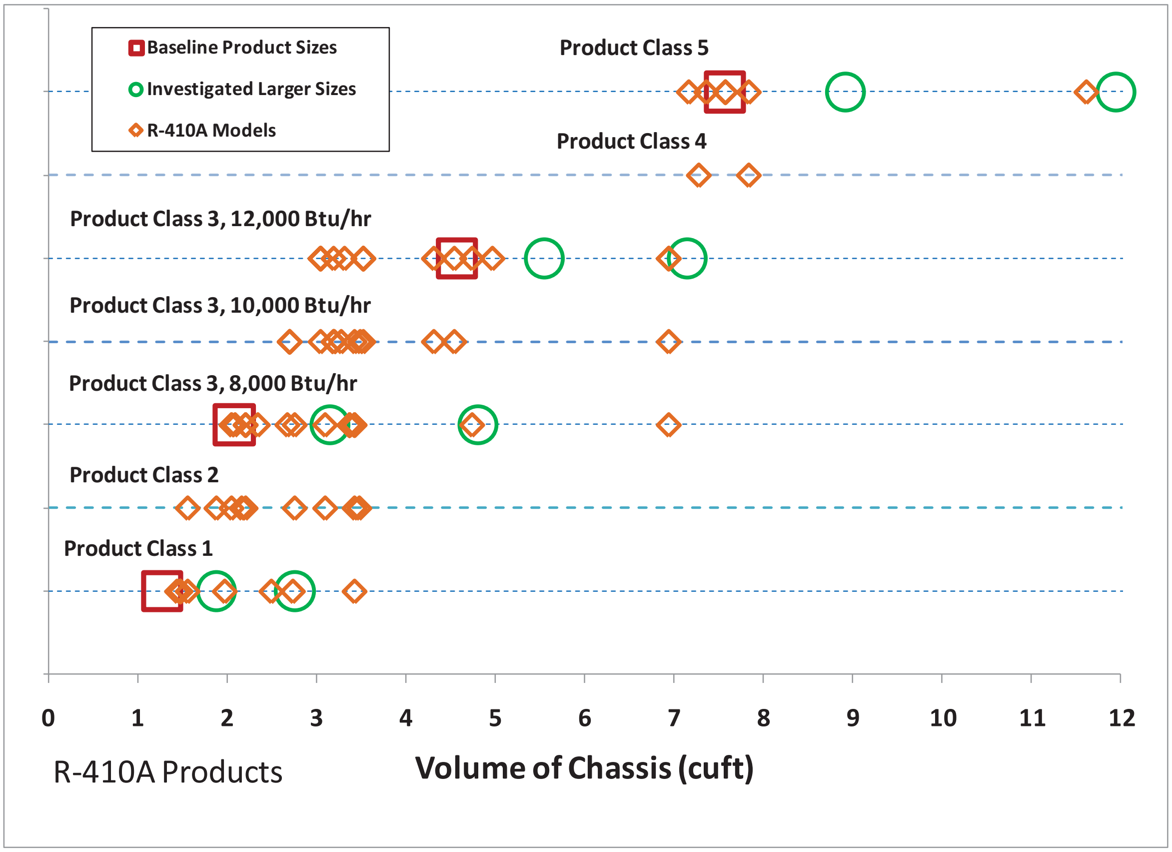


Figure 5.6.34 Size Distributions of Baseline-Efficiency Room Air Conditioners – R-410A Products on the Market

DOE observed that the physical sizes chosen for the analyzed baseline products matched the sizes of the smallest available baseline products well, except for the product class 3 unit of 12,000 Btu/h capacity. To adjust, DOE revised its analysis for this product class and capacity, using the 12,000 Btu/h R-410A baseline teardown product as a basis for the new analysis. The size data for this product is presented in Table 5.6.31 below.

Table 5.6.31 Adjusted Baseline Size for Product Class 3 – 12,000 Btu/h Analysis

	Width (*in*)	Height (*in*)	Depth (*in*)	Volume (*cf*)
Baseline PC3-12k Unit	19	14.5	21.25	3.39

Because of the split of product class 5, DOE also reviewed chassis sizes for the new product classes 5A (capacity between 20,000 and 27,999 Btu/h) and 5B (capacity larger than 27,999 Btu/h). DOE selected products of capacities 24,000 Btu/h 28,000 Btu/h room air conditioner to represent the analysis for these new product classes. DOE observed that no products on the market within the capacity range of the new product class 5A had chassis size near the roughly 12 cubic feet volume used as the maximum size in the DOE analysis. However, for products on the market with capacities within the range of the new product class 5B, this size level is required to achieve better than baseline efficiency, as shown in Table 5.6.32 below. Product 1 of this list is not within the product class 5B capacity range, but nevertheless, the largest chassis size is required for this product to achieve ENERGY STAR efficiency level.

Table 5.6.32 Product Class 5B – R-410A Product Sizes

	Capacity (*Btu/h*)	EER	Product volume (*cf*)
Product 1	27,800	9.7	11.6
Product 2	28,500	8.5	7.6
Product 3	36,000	8.5	11.6

DOE adopted the following approach for size selection of these product classes:

- For Product Class 5A, DOE did not consider growth to a volume near 12 cubic feet.
- For Product Class 5B, DOE did allow growth to this size.

The examined size increases in the final rule analysis are summarized in Table 5.6.33 below.

Table 5.6.33 Size Increases Examined During Room Air Conditioner Design Option Analysis

Design Description	Width *(inches (in))*	Height *(in)*	Depth *(in)*	Weight *(lb)*
Product Class 1				
Baseline	15.5	11.75	12	38.6
First Size Increase	18.5	12.5	14	42.7
Second Size Increase	19.69	13.63	17.72	46.8
Product Class 3, 8,000 Btu/h				
Baseline	18.5	12.5	15.5	49.4
First Size Increase	19.3	15.63	18	55.7
Second Size Increase	22.5	15.63	23.6	63.6
Product Class 3, 12,000 Btu/h				
Baseline	19	14.5	21.25	76.5
First Size Increase	23.5	15.63	23.6	81.2
Second Size Increase	26	15.63	28.4	87.6
Product Class 5A				
Baseline	26	17.69	28.41	129.2
First Size Increase	27.75	17.94	30.94	136.4
Second Size Increase	-	-	-	-
Product Class 5B				
Baseline	26	17.69	28.41	129.2
First Size Increase	27.75	17.94	30.94	136.4
Second Size Increase	29.81	22.38	30.94	156.5

DOE is aware that product size has a significant impact on efficiency, and requested comment during the preliminary analysis phase on acceptable maximum product sizes for louvered room air conditioners.

DOE received the following comments from stakeholders, on maximum product sizes:

- AHAM noted that smaller products (especially those in product classes 1 (room air conditioners without reverse cycle, with louvered sides, and capacities less than 6,000 Btu/h) and 2 (room air conditioners without reverse cycle, with louvered sides, and capacities 6,000 to 7,999 Btu/h)) would be most negatively impacted by an increase in weight. AHAM indicated that the Occupational Safety and Health Administration (OSHA) recommends an additional person for lifting and installing products weighing over 50 lbs. AHAM stated that the 50 lbs. limit is expected to influence consumer acceptance of these products.

- NPCC recommended that DOE compare the maximum unit dimensions in each preliminary analysis to the dimensions of the highest efficiency model available on the market. NPCC recommended that, if these two product dimensions are similar, that DOE assume that all units can be equally as large. NPCC also recommended that, if the market unit is smaller than the unit proposed by DOE, that DOE determine whether a redesign of the proposed unit would eliminate the size constraint.

DOE implemented the following changes in its analysis based on the comments submitted by stakeholders:

- DOE limited the maximum weight for product class 1 unit to 50 lbs., based on the Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) suggested weight limits.

- DOE adopted maximum product heights and widths consistent with max-tech products.

Further details of each analysis are detailed in the sections below.

50 lbs Weight Limit

NIOSH lists among its hazard evaluation checklist the handling of loads exceeding 50 lbs as a risk factor used to identify potential problems.[h] OSHA, in its *Ergonomics eTool: Solutions for Electrical Contractors*, states that lifting loads heavier than 50 lbs will increase the risk of injury, and recommends use of more than one person to lift weights greater than 50 lbs.[i] These

[h] http://www.cdc.gov/niosh/docs/2007-131/

[i] http://www.osha.gov/SLTC/etools/electricalcontractors/materials/heavy.html

guidelines calling for additional personnel for product lifting represent distinct changes in consumer utility for products that currently weigh less than 50 lbs.

DOE notes that all but the smallest room air conditioners weigh more than 50 lbs, a trend illustrated by the weights of the teardowns in Table 5.6.34 above. A summary of the baseline weights for each analyzed product class is included in Table 5.6.34 below.

Table 5.6.34 Baseline Product Weights of the Units for the Analyzed Product Classes

Product Class	Capacity (*Btu/h*)	Baseline CEER Analyzed Weight (*lb.*)*
1	5,200	40.0
3	8,000	50.1
3	12,000	68.03
5A	24,000	132.5
5B	28,000	140.3
8A	8,000	61.7
8B	12,000	67.4

*Product weights for the analyzed design options are calculated using the manufacturing cost model

DOE limited the total weight of the product class 1 baseline unit with integrated design options to 50 lbs, to avoid exceeding OSHA and NIOSH guidelines for single-person lifting. DOE did not consider limiting the weight of the other analyzed product classes, since they already exceeded this limit.

Maximum Chassis Sizes on the Market

DOE based the maximum chassis width and height of each analyzed product class on the dimensions of the largest R-410A room air conditioners in each product class on the market. DOE's maximum chassis sizes were based on HCFC-22 and R-410A products. Table 5.6.35 below compares DOE's max-tech design dimensions with the largest available products, for each product class. For each of these product classes, the physically largest product on the market also has the maximum available efficiency.

Table 5.6.35 Comparison of DOE Analysis Chassis Size and Market Chassis Size

Product Class	Large Chassis Size in DOE Analysis (*w x h x d*)	R-410A Max-Tech Unit on the Market (*w x h x d*)
1	19.69 × 13.63 × 17.72	19.75 × 14.0 × 21.38
3 (8000 Btu/h)	22.5 × 15.63 × 23.6	25.94 × 15.94 × 29
3 (12,000 Btu/h)	26 × 15.63 × 23.6	25.94 × 15.94 × 29
5A	27.75 × 17.84 × 30.94	26 × 17.5 × 29.75

5B	29.81 × 22.38 × 30.94	28 × 20.19 × 35.5

DOE chose maximum product heights and widths consistent with the largest products on the market. These dimensions set the face areas available for heat exchangers. However, DOE observed that the depths of the max-tech available products are significantly larger than expected—these depths are out of proportion when considering the relationship between depth and width or height of other products. DOE's analysis indicated that depths consistent with the proportions observed in most other products are sufficient to provide max-tech performance. Hence, DOE analysis selected max-tech design depths less than those observed in the max-tech available products. DOE used this approach for product classes 3 (room air conditioners without reverse cycle, with louvered sides, and capacities 8,000 to 13,999 Btu/h), 5A (room air conditioners without reverse cycle, with louvered sides, and capacities 20,000 to 27,999 Btu/h), and 5B (room air conditioners without reverse cycle, with louvered sides, and capacities 28,000 Btu/h or more). This limitation did not apply to product class 1 (room air conditioners without reverse cycle, with louvered sides, and capacities 5,999 Btu/h or less), for which growth was limited by consideration of the 50 lbs maximum weight.

Added Shipping Costs for Chassis Size Increases

The room air conditioner reverse-engineering included documentation of the packaging used for shipping the product, and additional accessories (remote control, window installation kit, bracing). As the chassis expands, the surrounding packaging also increases in size. The costs associated with all of these increases are part of the calculated incremental cost for the efficiency improvements. Most of the shipping material packaging cost is the cost of the surrounding cardboard box.

Most room air conditioners are shipped from overseas, and manufacturers mentioned during interviews the added shipping costs associated with larger chassis sizes. DOE calculated the cost of shipping to a U.S. distribution facility based on the size of the room air conditioner being shipped; the cost is determined based on the volume of the unit. This cost was reported separately from the manufacturing production cost (MPC). DOE expects that the manufacturer markup does not apply to this cost because manufacturers indicated that many room air conditioners are shipped by retailers. Hence, in determining the incremental cost associated with efficiency improvements, the shipping cost increase would be added to the incremental manufacturer sales price (MSP).

The shipping cost was determined as follows. DOE estimated the total shipping costs for a standard shipping container, based on interviews with manufacturers and quotes from shipping companies. The costs include shipping from the factory to a U.S. distribution facility. The number of units per container was calculated by volume, and divided by the cost of shipping to determine the cost of shipping per unit. For design options that involved increase in chassis size, DOE calculated incremental shipping costs to account for the larger size. The cost estimate including distribution within the U.S. is considered to be conservative, because part of this cost may already be included in the typical retailer markup, which has not be reduced to account for separate consideration of part of the shipping cost.

Increased Depth of Coil

DOE examined increasing the depth of the evaporator and/or condenser. Energy impacts were determined using the energy model, and cost impacts were determined using the manufacturing cost model. DOE determined that increasing coil depth beyond two tube rows generally is not effective in increasing EER. Most room air conditioners use heat exchangers with two tube rows, although some have more rows. However, the DOE analysis shows that the airflow reduction or fan power increase associated with increases in coil depth often negates the benefits of the additional heat exchanger surface area.

Increased Fin Density

DOE examined increases in fin density for all of the products. Energy impacts were determined using the energy model, and cost impacts were determined using the manufacturing cost model. DOE considered a maximum fin density of 22 fins per inch (FPI). In some cases, increasing fin density improves performance. For many cases, the airflow resistance of the additional fins leads to reduced airflow and/or higher fan power which negates the benefit of the increased heat exchanger surface area. Many units already use high fin densities, so increased fin density often results in minimal or no gains. Lastly, high fin densities have been mentioned by manufacturers as having potential detrimental effects on long-term unit efficiency, since cleaning coils with high fin densities is very difficult.

Add Subcooler to Condenser Coil

DOE examined the use of subcoolers for all room air conditioners. Energy impacts were determined using the energy model, and cost impacts were determined using the manufacturing cost model. DOE used a subcooler exit temperature of 95 °F, based on information provided by manufacturers.[5] In all cases, the subcooler made a small improvement in efficiency, but was highly cost-effective. Inspection of the teardown units revealed that many high-efficiency units placed the subcooler within the condenser plenum. DOE determined that the addition of a subcooler to a unit would not require any chassis size increase.

In selecting the appropriate subcooler length for each product class, DOE considered the subcoolers from the teardown units. In each product class, the highest-efficiency unit contains a subcooler. The length of this subcooler provided the basis for the length of the subcooler added for a product of the same capacity. In some cases DOE determined that the chosen subcooler length was excessive for the baseline chassis size. DOE reduced the selected length and performance of the subcooler in these cases. DOE maintained a fixed subcooler length with subsequent chassis size increases.

Microchannel Heat Exchangers

DOE analyzed microchannel condensers as a design option during the preliminary analysis. Performance modeling of microchannel heat exchangers is included in the upgraded room air conditioner energy model. Information provided from vendors indicates that, in most cases, this technology is not suitable for evaporators because (1) the geometry is not suitable for quick drainage of condensate from the heat exchanger surface; and (2) uniform refrigerant distribution into the many parallel tubes is not assured. Therefore, microchannel heat exchangers were considered only for condensers. Use of this technology resulted in a small efficiency improvement in most of the analysis. DOE determined microchannel condenser incremental manufacturing costs based on prices provided by a vendor for two representative sizes, one suitable for a 5,000 Btu/h room air conditioner and the other suitable for a 24,000 Btu/h unit, assuming high-volume production. In addition to purchase price, the costs also incorporate the cost of brazing two pieces of copper tubing to the all-aluminum microchannel heat exchanger, since many purchasers do not have the capability of brazing copper to aluminum and such fabrication would represent an additional step in the manufacturing process.

The sizes and cost estimates of the microchannel heat exchanger designs considered in the analysis are presented in Table 5.6.36 below. For the most part, the costs are an order of magnitude greater than that of any of the other design options considered. The table also shows the modeled efficiency improvements calculated for this design option. The improvements were low or zero.

Table 5.6.36 Microchannel Condenser Costs - Preliminary Analysis

Room Air Conditioner Capacity *(Btu/h)*	**Condenser Core Dimensions** *(Height x Length, in)*	**Condenser Core Depth** *(in)*	**Cost**	**EER Increase Benefit from Baseline**
5,000	11.25 × 15.25	1	$75	0.3
8,000	12.75 × 17.25	1	$85	-
12,000	16 × 21.63	1	$110	-
24,000	16.37 × 22	1	$115	0.1

Improved Fan/Blower Motor Efficiency

Room air conditioners almost exclusively use double-shafted PSC motors to power the condenser fan and evaporator blower. DOE considered improved motor efficiency as a design option, in the form of high efficiency PSC motors and brushless DC (BLDC) motors. DOE considered the cost of the motors as a function of motor type, shaft power, and efficiency, although only one efficiency level was considered for BLDC motors. DOE obtained cost data from vendors, both for room air conditioner motors and for single-shaft motors with similar power output and speed used in other applications. DOE selected a typical range of motor shaft power rating for each product class it analyzed, based on the motors used in the teardown units, and sought information about similar motors at higher efficiencies. The selected shaft power levels are shown in Table 5.6.37 below.

Table 5.6.37 Motor Power Rating by Product Capacity

Room air conditioner capacity *(Btu/h)*	**Fan Motor Shaft Power Rating** *(W)*
<6,000	25-35
8,000 to 13,999	60-75
>20,000	150-200

DOE selected a motor efficiency of 50 percent for the PSC motors of baseline room air conditioner. This was consistent with the motors in the teardown units, as well as the information obtained during manufacturer interviews. DOE selected a peak PSC motor efficiency of 70 percent for the analysis.

BLDC motors are a more efficient alternative to PSC motors, and BLDC motors are used in similar applications, such as packaged terminal air conditioners (PTACs). DOE obtained information about BLDC motors from motor vendors, motor catalogs, and discussions with room air conditioner manufacturers. Reported BLDC motor efficiencies were in the range 75 percent to 90 percent. DOE selected an efficiency level of 80 percent for the analysis.

DOE examined PSC motor prices from a wide variety of motor vendors. DOE conducted analysis on this motor data to establish a robust correlation for motor cost based on motor characteristics including efficiency, shaft power, weight, current, and voltage. The assessment included single-shafted and double-shafted PSC motors intended for HVAC applications. DOE found the strongest correlation between motor price and weight, and used this relationship as the basis for calculating the incremental costs for PSC motor efficiency improvements. Figure 5.6.35 below shows the calculated cost of increasing the efficiency of a PSC motor from 50 percent to 70 percent as a function of motor shaft power output, for shaft outputs from 20 W to 100 W. This range included motors for product classes 1, 3 and 8. For the product class 5 baseline motor, with a rated shaft output of 200 W, DOE extrapolated the cost of the motor from the smaller motor sizes. Further information on the assessment of PSC motor costs is available in appendix 5D of this TSD.

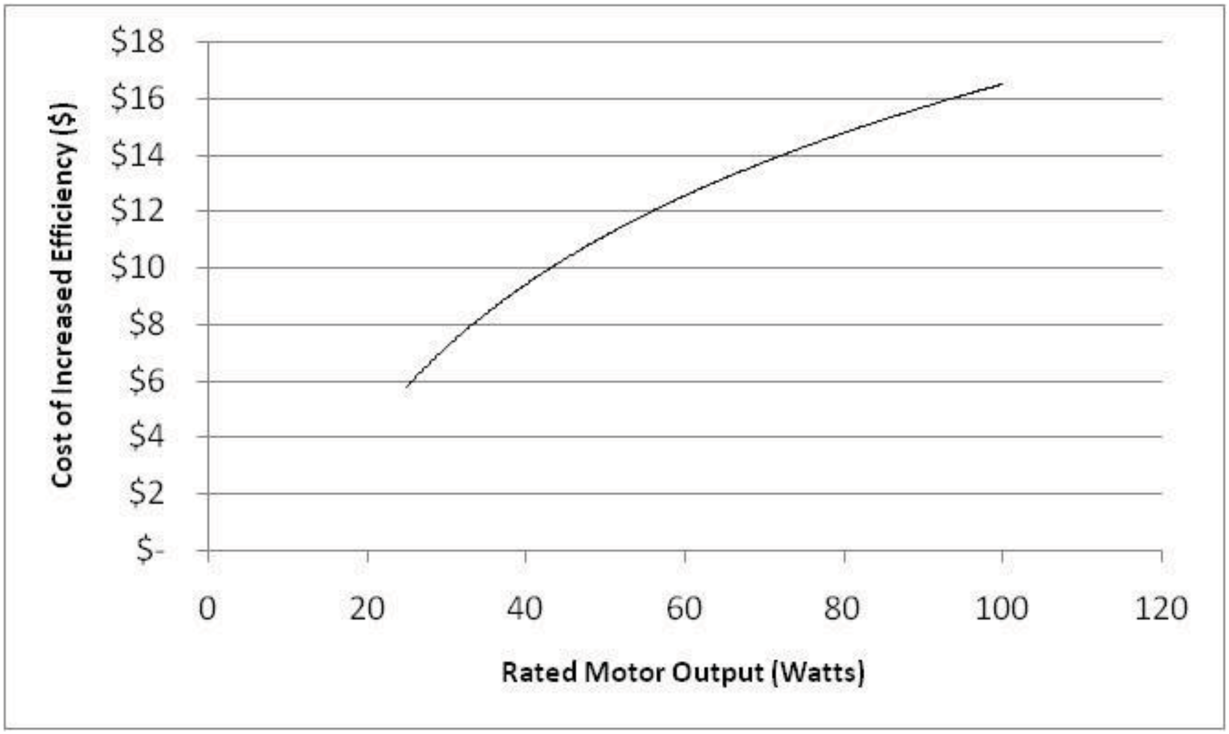


Figure 5.6.35 Cost Differential for Increasing PSC Motor Efficiency from 50% to 70%

DOE also compiled pricing and size information on BLDC motors from motor vendors and catalogs. DOE found prices for BLDC motors with the same motor shaft output as the PSC motors found in the reverse engineering units, and calculated the cost of replacing the baseline PSC motors with the BLDC motors. Figure 5.6.36 below shows the calculated cost of replacing a baseline PSC motor with a BLDC motor.

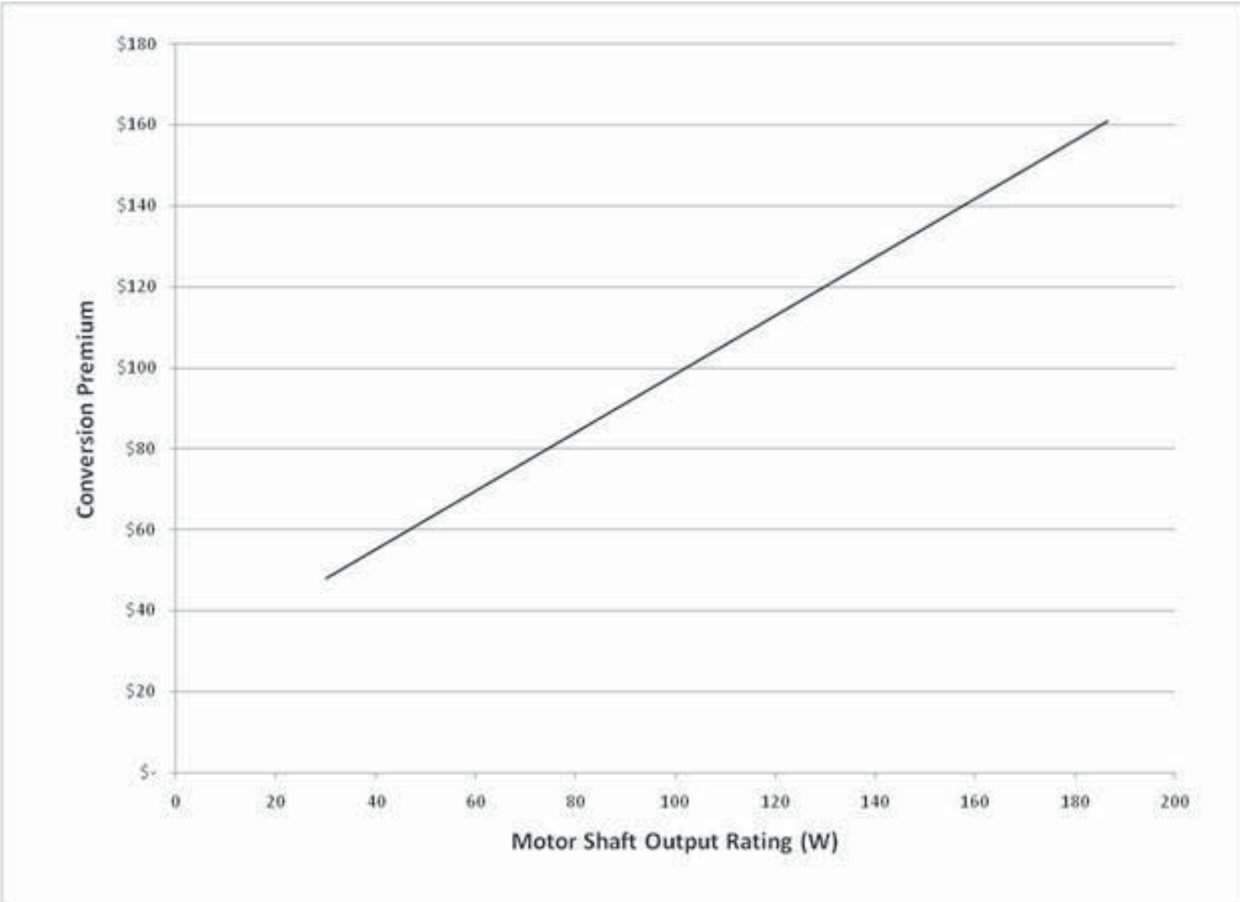


Figure 5.6.36. Cost Differential for Replacing a Baseline PSC Motor with a BLDC Motor.

Some manufacturers raised concerns regarding the use of BLDC motors, stating that they are physically much larger than PSC motors and thus may not fit into the small space allowed in a room air conditioner. Table 5.6.38 shows the characteristics of a typical 70 W PSC motor, and the characteristics of a typical 70 W BLDC motor observed by DOE. These ranges are derived from motor vendor catalog data. The data show that the BLDC motor has greater weight and length than the comparable double-shafted PSC motor. However, DOE did not conclude that the size increase of these motors would prevent their use in room air conditioners.

Table 5.6.38 Comparison of a typical range of sizes for a 70W PSC Double-Shafted Motor and a 70W BLDC Motor

Typical Characteristics	Double-Shafted PSC	BLDC
Typical Efficiency	50%	80%
Weight	8–10 lbs.	12 lbs.
Outer Diameter	3.75–5.0 in	1.73–2.63 in
Motor Length (w/o Shaft)	3.0–4.25 in	4.5–6.39 in

Improved compressor efficiency

DOE conducted the engineering analysis based on use of R-410A refrigerant, since this is the refrigerant currently used by all new room air conditioners

During the preliminary analysis, DOE sought information on the performance of R-410A rotary compressors of varying efficiency levels for all of the products under analysis. In many cases, the range of efficiency for which vendors were willing to provide performance data was limited. Conducting the analysis generally required knowledge not just of design point capacity and EER—DOE requested performance data for a representative range of evaporating and condensing conditions, as required for input into the energy model. In some cases, the trends of compressor performance as a function of operating conditions were extrapolated from the trends exhibited by a compressor of the same refrigerant of nearly the same capacity. For product class 5, DOE also analyzed scroll compressors as a design option. The EER and capacity of the compressors for which DOE obtained performance data are illustrated in Figure 5.6.37 below. As can be seen, there were data for many more HCFC-22 compressors than for R-410A rotary compressors. The EER ratings of the R-410A compressors were not only generally lower than those of HCFC-22 rotary compressors of similar capacity, but exhibited a much more limited EER range (*i.e.*, HCFC-22 compressor EER levels ranged from 9.0 to 11.2 near 5,000 Btu/h nominal capacity, whereas the R-410A compressor EER range was roughly 9.0 to 10.0). The chart shows that reduction in the EER when switching to R-410A compressors was greater for lower capacities than for higher capacities. The chart also shows that the use of scroll compressors does not improve efficiency for most of the capacity range of interest for room air conditioners.

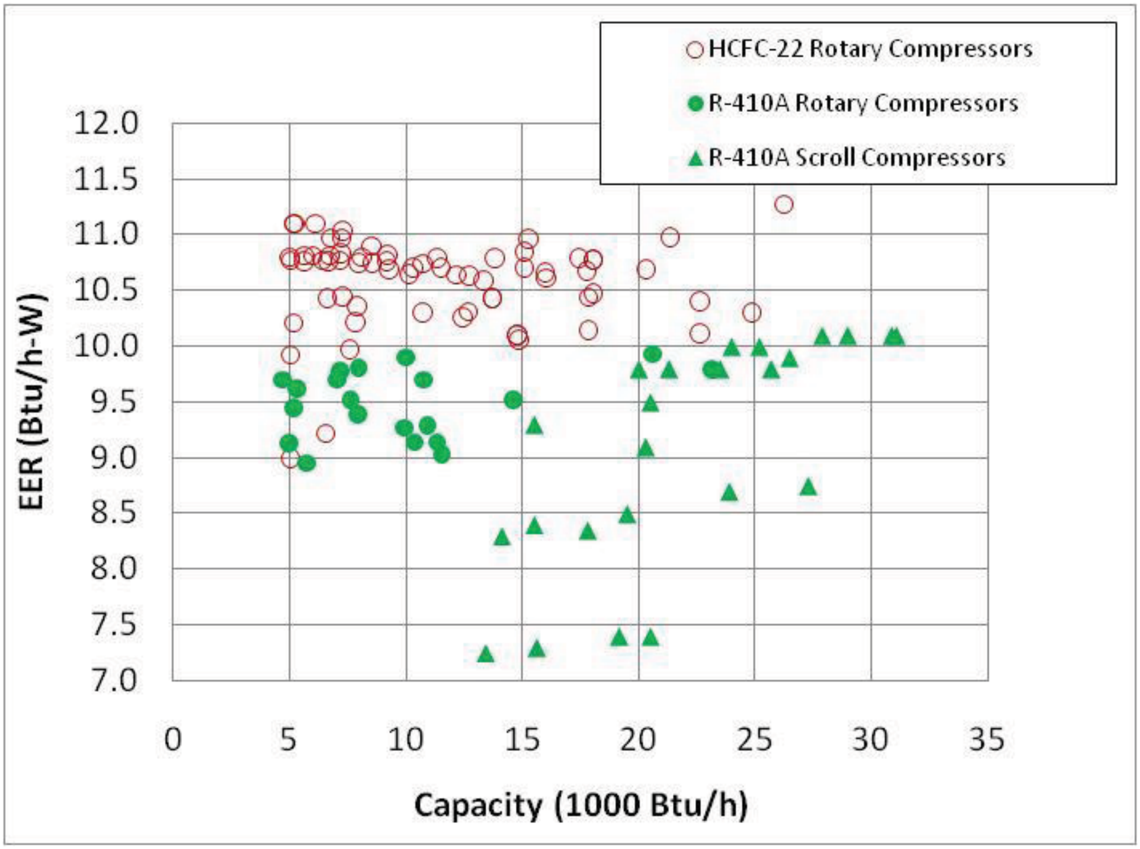


Figure 5.6.37 Compressor Performance Specifications – Preliminary Analysis

During the final rule analysis, DOE again reviewed R-410A compressors, checking vendor websites and speaking with vendor representatives about performance of commercially available, developmental, and future compressors. Website data for R-410A compressors are illustrated in Figure 5.6.38 below.

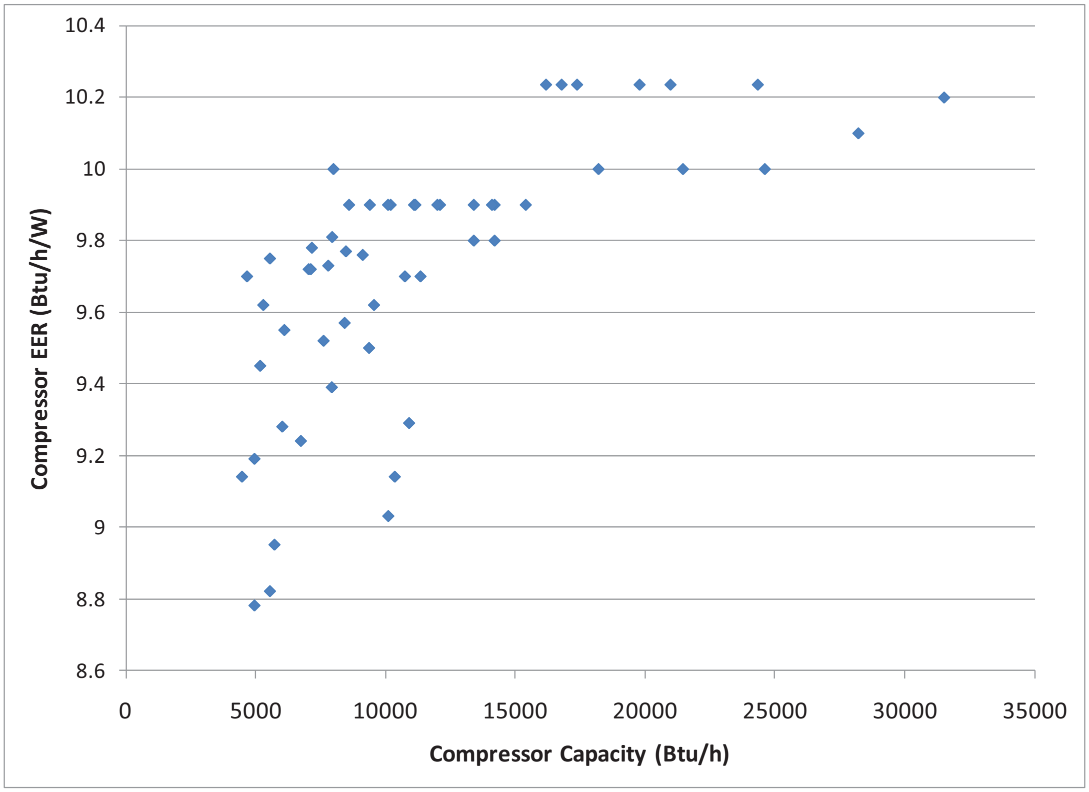


Figure 5.6.38 R-410A Compressor Performance Characteristics – Final Rule Analysis

Based on DOE's research and manufacturer interviews (see above), DOE decided to consider maximum compressor-rating EER of 10.0 for lower-capacity compressors, and EER of 10.3 for higher-capacity compressors. The data clearly showed availability of R-410A compressors spanning a range of EER, so DOE added "high efficiency compressor" as a design option in the analysis. The maximum EERs considered for the analyzed product classes are listed in Table 5.6.39 below.

Table 5.6.39 Maximum Compressor EER Levels

Product Class	Maximum Compressor EER in Final Rule Analysis
1,3,8A,8B	10.0
5A,5B	10.3

DOE used detailed performance maps data (capacity and EER as a function of suction and discharge pressures) to model many of the compressors. However, in some cases, where such detailed data was not available from vendors, DOE used maps of compressors with nearly the same capacity or EER, adjusted for the modeled compressor's design-point performance.

The relationship between R-410A compressor cost and baseline-efficiency room air conditioner capacity that DOE used in the analysis is illustrated in Figure 5.6.39 below. This relationship was developed based on information collected during past rulemakings, discussions with manufacturers, and cost information provided by compressor vendors. It includes the 10 percent cost premium for R-410A compressors discussed in section 5.6.2.5. The figure is based on room air conditioner capacity, and not compressor rating point capacity.

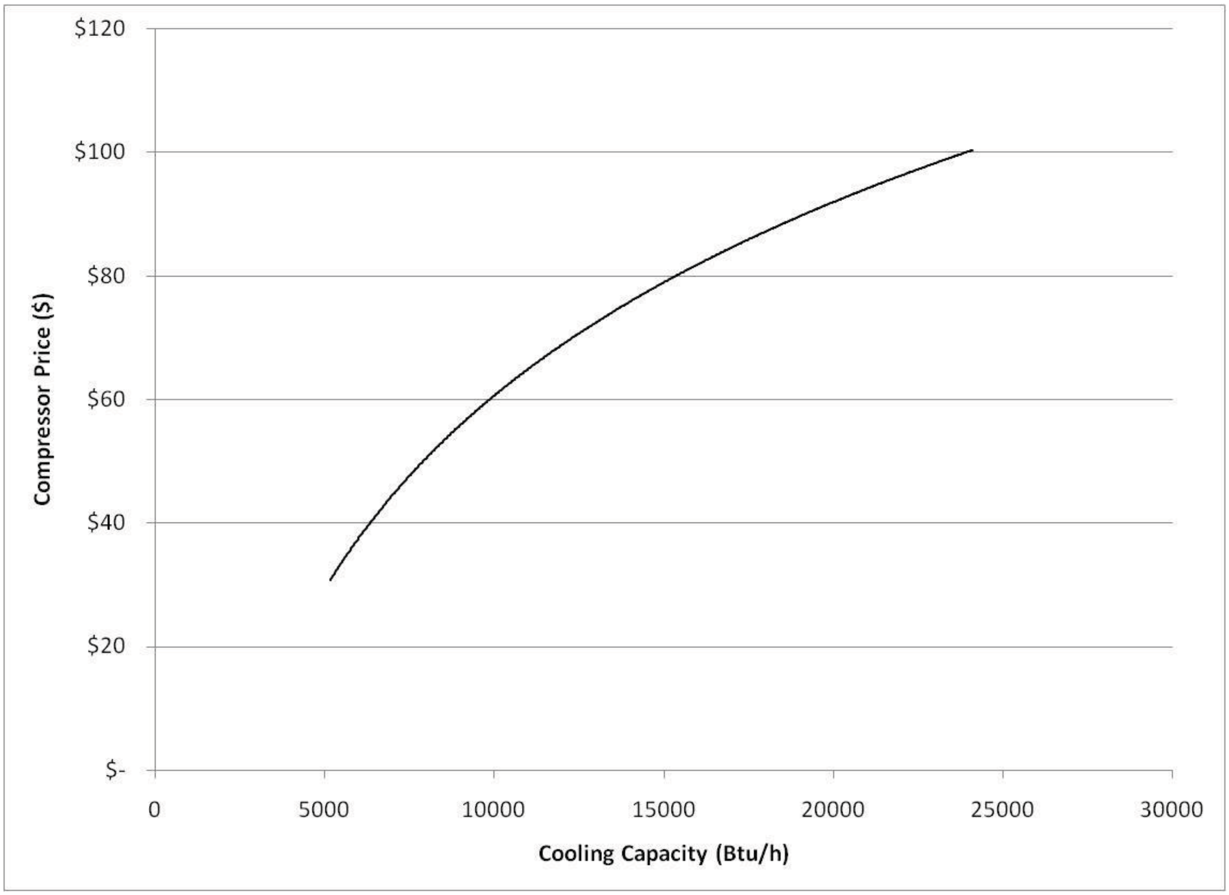


Figure 5.6.39 R-410A Compressor Cost

Scroll Compressors

During the preliminary analysis phase, DOE considered scroll compressors as a design option for product class 5. However, scroll compressors do not provide additional efficiency above the 10.3 maximum EER considered in the analysis for rotary compressors. They are also heavier and more costly. Thus, for the final rule analysis, DOE did not consider scroll compressors as a cost-effective design option in room air conditioners.

Standby Mode and Off Mode

DOE identified and analyzed only one option for reducing standby and off mode energy use–changing from a transformer-based power supply to a switching power supply. DOE conducted energy measurements of electronic boards, and determined that the total standby mode power for a typical baseline control board is roughly 1.4 W, and that the transformer consumes about 75 percent of this power. DOE concluded that the main source of power consumption in standby mode for a room air conditioner is the power supply, as shown in Table 5.6.40. The measurements reported in this table were made by disconnecting more loads for the successive measurements, thus showing that nearly 1 W of the 1.32 W associated with the standby mode for this unit represents the transformer loss (the transformer loss could actually be a larger portion of the 1.32 W, since disconnecting the loads as indicated reduces power supplied by the transformer, and thus could also be reducing the its loss in the successive measurements).

Table 5.6.40 Standby Energy Consumption by Component

Example Stand-by Energy Breakdown for Electronic Board	
Components Energized	**Power Consumption (*W*)**
User Interface Board + Control Board	1.32
Control Board	1.28
Transformer	0.96

Two of the teardown units with electronic control boards used switch-mode power supplies, an alternate technology to the traditional linear regulated power supply. The switching power supply replaces the traditional power supply with a more complex circuit board and a much smaller transformer. The two switching power supply units consumed roughly 0.7 W.

DOE obtained conversion cost information for switching power supplies for cell phone technology, based on similar production volumes and power levels as for room air conditioner control board power supplies. During the preliminary analysis, the increase in direct material costs for converting to a switch-mode power supply based on this information was estimated at approximately $1.00. DOE updated its cost-model, reviewed additional teardown information for these units and reviewed the incremental costs of this technology for similar household appliances, and adjusted its estimate to $0.75 for the final analysis.

5.6.2.7 Summary of Analysis Adjustments

During the final rule analysis, DOE revised its preliminary analysis based on new information collected in 2010, based on investigation of the room air conditioner market after the R-410A conversion. Key changes in the analysis are listed in Table 5.6.31 below.

Table 5.6.41 Summary of Key Adjustments to the Engineering Analysis during Final Rule Analysis

Topic	Preliminary Analysis	Changes made in the final rule analysis
Product Classes	Full analysis of existing product classes 1,3,5,8	Full analysis of product classes 1,3, 5A, 5B, 8A, 8B
Compressor Efficiency	Used available R-410A compressor data, which was limited	Maximum compressor nominal EER of 10.0 for product classes 1, 3, 8A, and 8B; and 10.3 for product classes 5A and 5B
Size Limits for Products with Louvered Sides	Based on the range of sizes of available products	50 lbs weight limit for product class 1 Maximum height and width consistent with available max-tech products, maximum depth consistent with typical depth/height/width ratios.
Chassis Design	Based on baseline units analyzed	Chassis thicknesses were adjusted based on the calculated weight of each unit, in accordance with teardown analysis. Chassis design was also adjusted from simple basepan design to welded box design as needed.
Scroll Compressors	Considered for product class 5	Not considered.
Cost-Model Material and Labor Costs	Costs updated as of 2008	Costs updated as of 2010

As part of the analysis of product class 1 for this final rule, DOE made adjustments to the product design of the 6,000 Btu/h 12.0 EER unit used as the max-tech model for the product class 1 cost-efficiency curve. These adjustments reflected an adjustment in the capacity of the unit from 6,000 Btu/h to 5,000 Btu/h. DOE adjusted the cost-efficiency curve for product class 1 based on this analysis, and then applied the 50 lbs product limit suggested by stakeholders. DOE noted that the 12.0 EER product that was reverse-engineered did not incorporate all of DOE's analyzed design options, and so the calibration did not only apply to the max-tech of the cost-efficiency curve, but to some intermediate steps as well. The product 1 max-tech level of 11.8 is a product of both this calibration and the 50 lbs product limit.

5.6.2.8 Active Mode Analysis

The cost-efficiency curves based on the active mode metric (EER) are shown in Figure 5.6.40 through Figure 5.6.46 below. The cost axis of these charts represents MSP plus shipping cost. Note that AHAM did not receive a sufficient number of responses regarding costs from manufactures to allow aggregation of this data for submission to DOE. Hence, there is no AHAM data to allow comparisons. The figures do, however, compare preliminary-analysis and final rule analysis results. Each separate point in the plots represents a different design configuration, rather than a specific efficiency level.

Most of the final rule analysis curves are shifted to a higher cost as compared with the preliminary analysis results. The key exception is the 12,000 Btu/h product class 3 analysis, for which DOE decreased the baseline chassis size, using information from the teardown of a 12,000 Btu/h R-410 product.

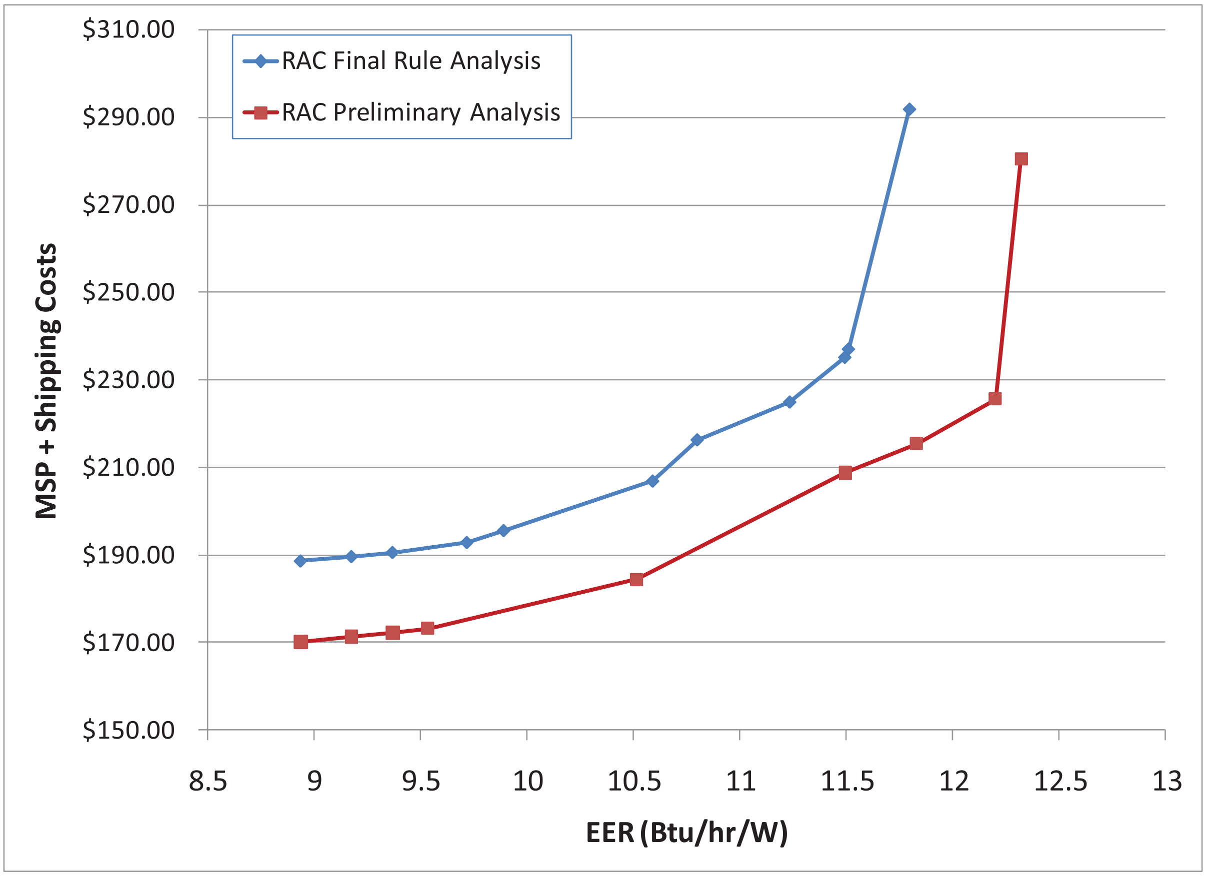


Figure 5.6.40 Product Class 1 Cost-Efficiency Curve

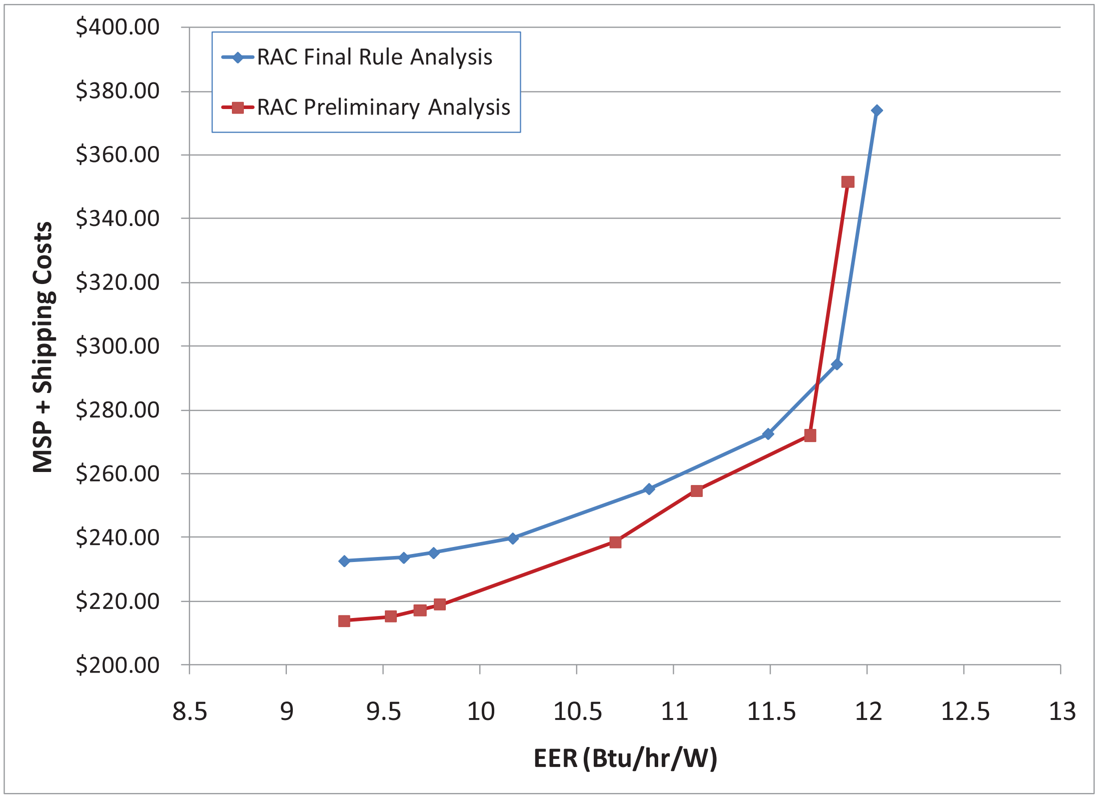


Figure 5.6.41 Product Class 3 - 8,000 Btu/h Capacity Cost-Efficiency Curve

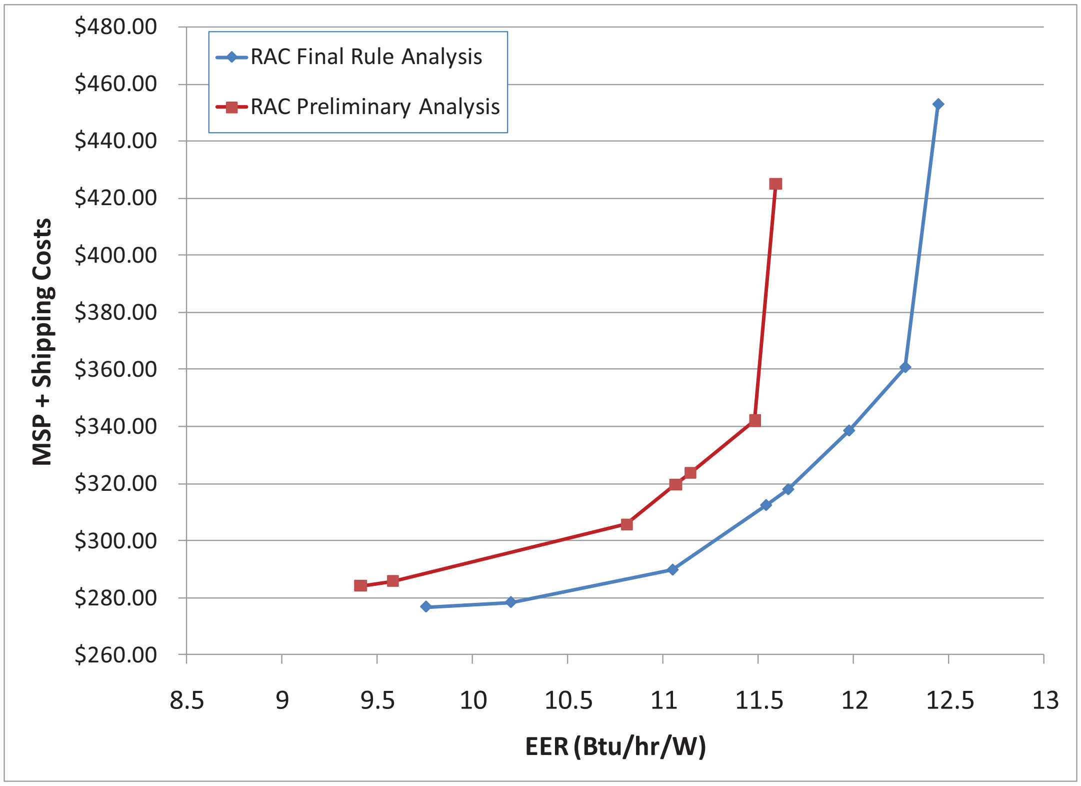


Figure 5.6.42 Product Class 3 - 12,000 Btu/h Capacity Cost-Efficiency Curve

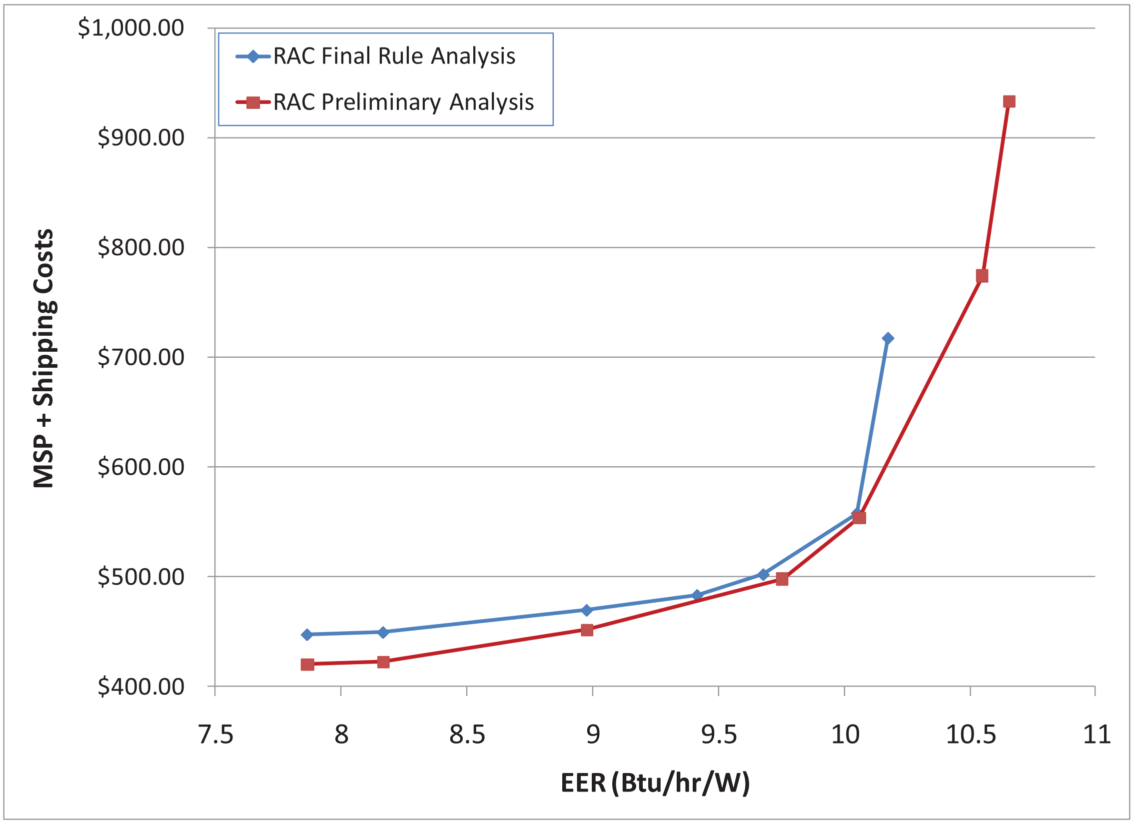


Figure 5.6.43 Product Class 5A – 24,000 Btu/h Cost-Efficiency Curve

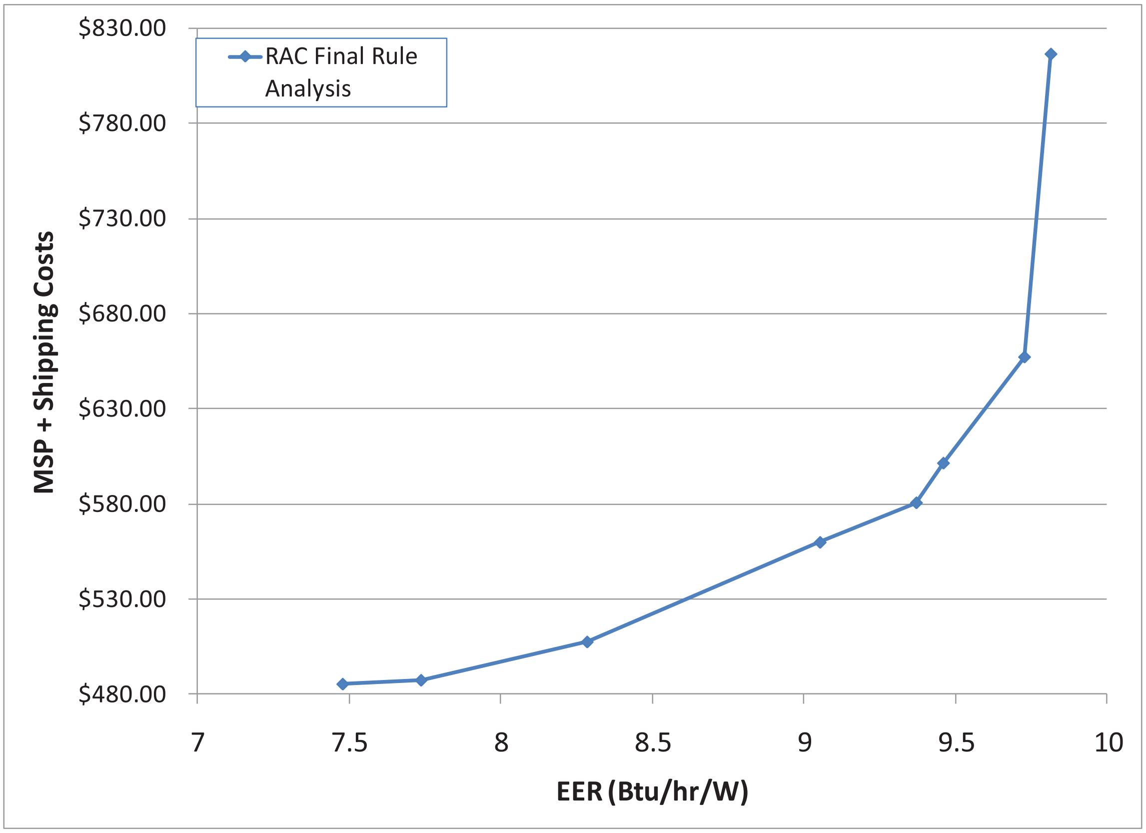


Figure 5.6.44 Product Class 5B – 28,000 Btu/h Cost-Efficiency Curve

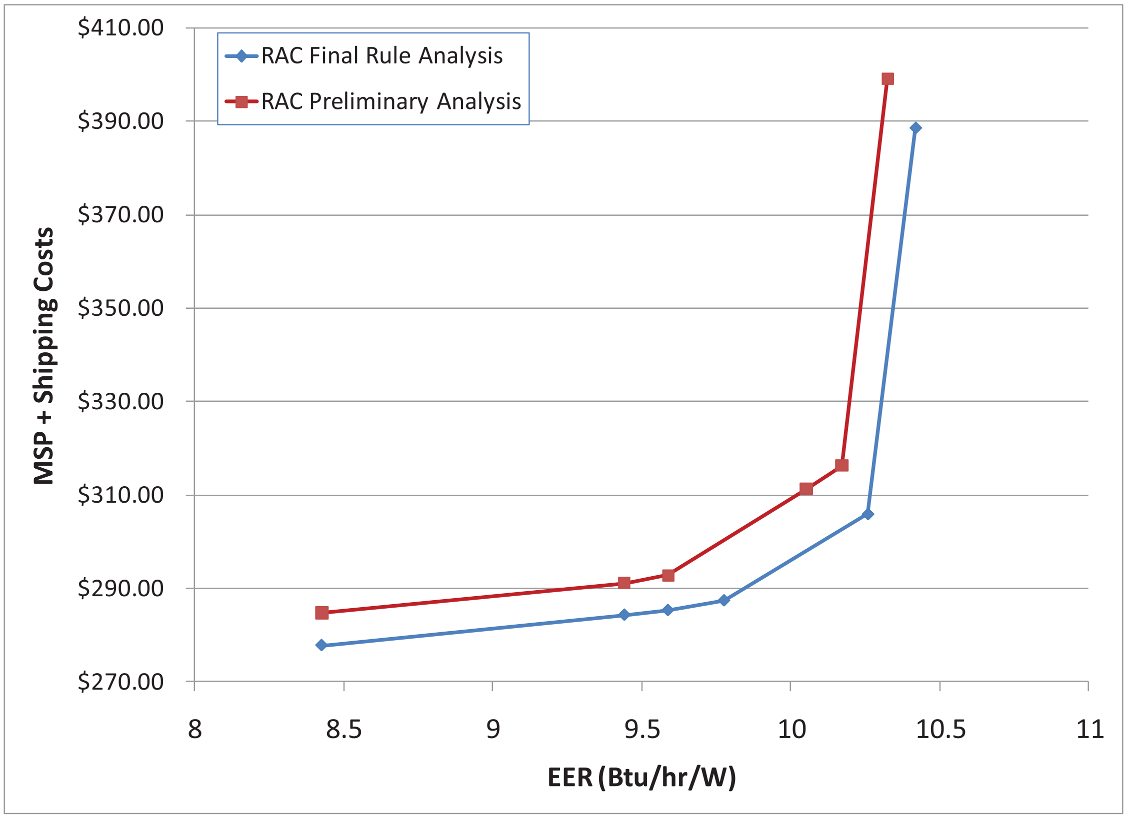


Figure 5.6.45 Product Class 8A - 8,000 Btu/h Capacity Cost-Efficiency Curve

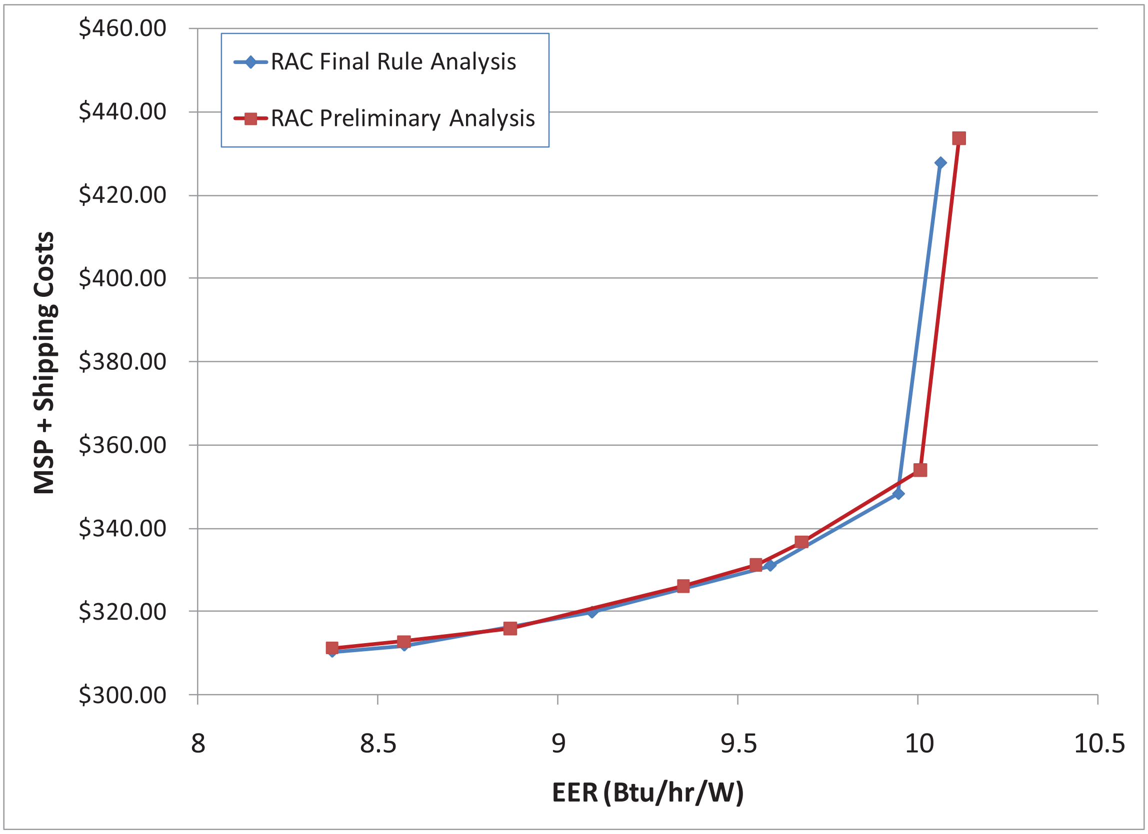


Figure 5.6.46 Product Class 8B - 12,000 Btu/h Capacity Cost-Efficiency Curve

5.6.2.9 Incremental Costs by CEER

The previous section discusses costs associated with increase of the active mode efficiency, measured in EER. As discussed in section 5.4, the analysis for this rulemaking is based on the integrated metric, CEER. DOE analyzed the improvement in CEER associated both with design options that improve EER and design options that reduce standby power. DOE developed overall cost-efficiency relationships for CEER by combining these analysis. In this overall analysis, DOE chose to implement the design options in order of decreasing cost-effectiveness. The reduction in standby power had cost-effectiveness between that of the best and worst active mode design options. This is illustrated for the product class 1 analysis in Figure 5.6.47 below. The plot shows the incremental CEER improvement of the design option divided by incremental manufacturing production cost (MPC) associated with the design option, for the final analysis.

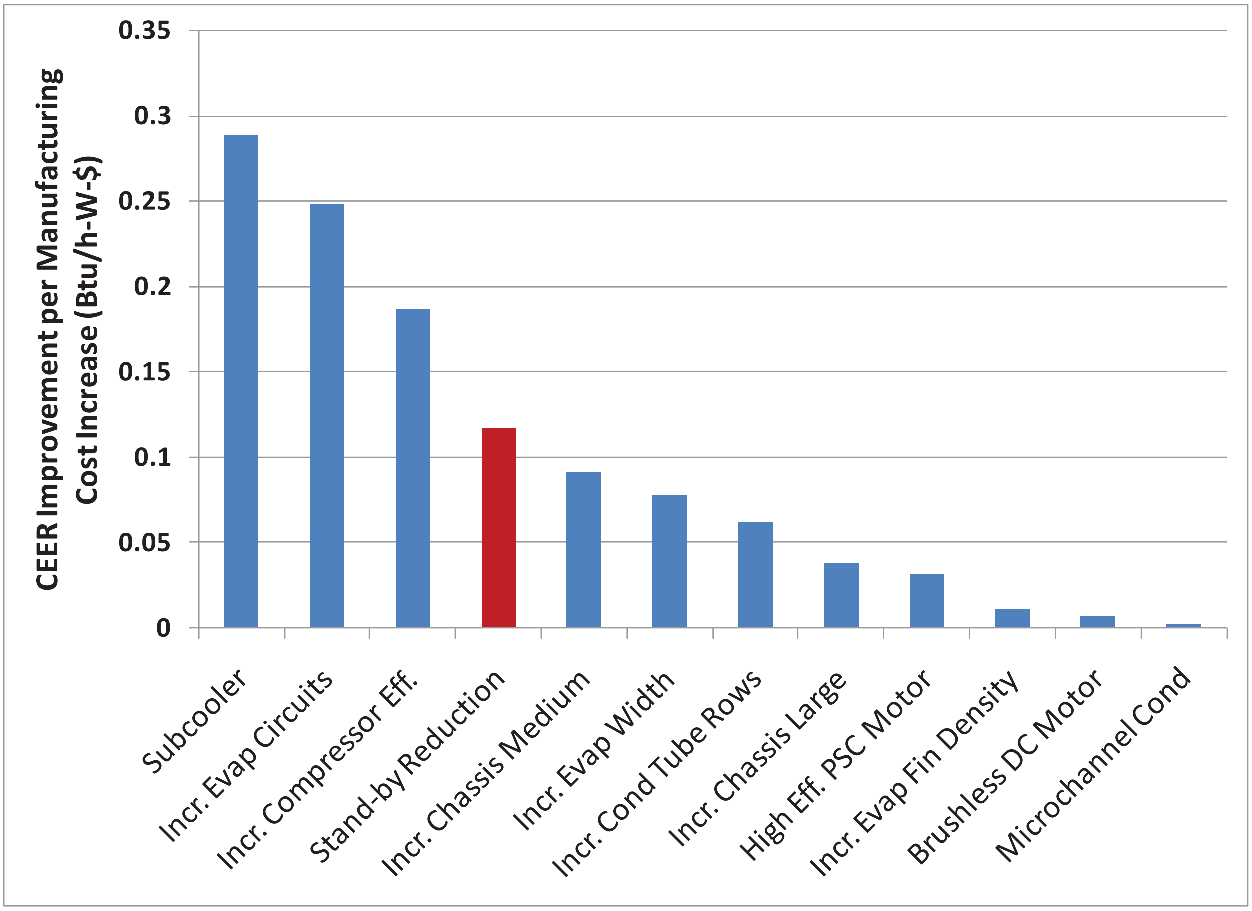


Figure 5.6.47 Comparison of the Cost-Effectiveness of Active and Standby Mode Design Options

As discussed above, DOE determined that the incremental cost for reducing standby mode power consumption from 1.4 W to 0.7 W is $0.75. Table 5.6.42 below summarizes this incremental cost.

Table 5.6.42 Room Air Conditioner Cost-Standby/Off Mode Power Relationship

Standby Level	Power *(W)*	Incremental Cost
Baseline	1.4	$0
1	0.7	$0.75

Table 5.6.43 through Table 5.6.49 present DOE's estimates of incremental cost in terms of MPC for improvement of room air conditioner CEER above the baseline. DOE updated this analysis from the preliminary analysis based on information collected during the final rule analysis phase. For the final rule analysis, DOE calculated the incremental costs for product classes 1, 3 (8,000Btu/h and 12,000Btu/h), 5A, 5B, 8A, and 8B. The incremental costs start at zero additional cost for the baseline R-410A unit.

The tables also present the calculated shipping cost at each efficiency level, based on the shipping package size. The first level of each table reflects the calculated CEER of a unit with a baseline EER rating and a standby power consumption of 1.4 W. The cost for this level represents the estimated cost associated with regaining the current standard EER level with the new refrigerant. DOE calculated the costs for each CEER level based on appropriate selection of active mode and standby mode design options. In cases where the CEER efficiency level does not coincide with the CEER determined for the design configuration directly analyzed with energy and manufacturing cost modeling, DOE took the following approach. If the next design option could be partially applied, DOE interpolated between costs and CEER levels calculated for the nearest design configurations. This approach applied to heat exchanger or chassis size increases, PSC motor efficiency improvement, and addition of a subcooler. In cases where the next design option could not be partially applied, the full cost of the design option was applied. This approach applied to increase in the number of heat exchanger circuits, change in heat exchanger tube size, and switch to BLDC motor technology.

Table 5.6.43 Room Air Conditioner Cost-Efficiency Relationships for Product Classes 1

Product Class 1: Without Reverse Cycle, With Louvered Sides, < 6,000 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	9.52	$0.00	$3.86
1	10.1	$6.31	$4.68
2	10.6	$13.53	$7.22
3	11.1	$22.72	$8.39
4	11.4	$32.32	$8.39
5	12.7	$75.82	$8.39

Table 5.6.44 Room Air Conditioner Cost-Efficiency Relationship for Product Class 3 – 8,000 Btu/h Capacity Unit

Product Class 3 – 8,000 Btu/h: Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	9.69	$0.00	$6.32
1	10.2	$5.30	$6.76
2	10.7	$12.30	$9.11
3	10.9	$15.95	$9.58
4	11.5	$30.92	$10.91
5	12.0	$103.87	$14.63

Table 5.6.45 Room Air Conditioner Cost-Efficiency Relationship for Product Class 3 – 12,000 Btu/h Capacity Unit

Product Class 3 – 12,000 Btu/h: Without Reverse Cycle, With Louvered Sides, 8,000 - 13,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	9.72	$0.00	$10.33
1	10.2	$2.00	$10.33
2	10.7	$7.42	$10.33
3	10.95	$9.33	$10.33
4	11.5	$29.43	$10.33
5	12.0	$47.81	$16.08

Table 5.6.46 Room Air Conditioner Cost-Efficiency Relationships for Product Class 5A – 24,000 Btu/h

Product Class 5A: Without Reverse Cycle, With Louvered Sides, 20,000 to 27,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	8.47	$0.00	$24.79
1	9.0	$8.85	$27.22
2	9.4	$19.04	$27.22
3	9.8	$50.66	$27.22
4	10.15	$204.62	$27.22

Table 5.6.47 Room Air Conditioner Cost-Efficiency Relationships for Product Class 5B – 28,000 Btu/h

Product Class 5B: Without Reverse Cycle, With Louvered Sides, ≥ 28,000 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	8.48	$0.00	$29.75
1	9.0	$23.52	$36.15
2	9.4	$50.27	$36.46
3	9.8	$229.01	$36.46

Table 5.6.48 Room Air Conditioner Cost-Efficiency Relationship for Product Class 8A – 8,000 Btu/h

Product Class 8A – 8,000 Btu/h: Without Reverse Cycle, Without Louvered Sides, 8,000 – 10,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	8.41	$0.00	$12.26
1	9.3	$4.61	$12.26
2	9.6	$6.68	$12.26
3	10.0	$16.63	$12.26
4	10.4	$88.45	$12.26

Table 5.6.49 Room Air Conditioner Cost-Efficiency Relationship for Product Class 8B – 12,000 Btu/h

Product Class 8B – 12,000 Btu/h: Without Reverse Cycle, Without Louvered Sides, 11,000 – 13,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	8.44	$0.00	$12.26
1	9.3	$11.72	$12.26
2	9.5	$15.39	$12.26
3	9.8	$26.06	$12.26
4	10.0	$93.36	$12.26

DOE used consolidated product class 3 results in the downstream analysis. The consolidated results are the average of results of the two product capacities examined. The incremental cost averages for product class 3 are shown in Table 5.6.50 below.

Table 5.6.50 Room Air Conditioner Cost-Efficiency Relationship for Product Class 3 – Average

Product Class 3 – Average: Without Reverse Cycle, With Louvered Sides, 8,000 – 13,999 Btu/h			
Efficiency Level	**CEER**	**MPC Increase**	**Shipping Costs**
Baseline	9.71	$1.25	$8.33
1	10.2	$4.90	$8.55
2	10.7	$11.11	$9.72
3	10.9	$13.89	$9.95
4	11.5	$31.43	$10.62
5	12.0	$77.09	$15.36

The incremental cost data for active mode design options are detailed further in appendix 5D of this TSD. The appendix also provides incremental cost data for both the integrated metric (CEER) and non-integrated metric (EER).

5.6.2.10 Product Class Modifications

As discussed above, DOE is making changes to the existing product class structure for room air conditioners. During the preliminary phase, DOE proposed no changes to the existing product class structure. DOE received one comment addressing product classes during the preliminary analysis comment period from AHAM, and one comment after the end of the comment period titled, "Agreement on Minimum Federal Efficiency Standards, Smart Appliances, Federal Incentives and Related Matters for Specified Appliances" from a group of joint petitioners representing manufacturers, industry representatives, and efficiency and consumer advocates. This latter group is referred to as the Joint Petitioners. The comments were as follows:

- AHAM recommended that product class 5 be split into two product classes based on product cooling capacity, the first class including products with capacity from 20,000 Btu/h to 24,999 Btu/h, and the second with capacity greater than 25,000 Btu/h. AHAM also recommended that product class 8 be split into two product classes, the first with capacity from 8,000 Btu/h to 10,999 Btu/h, and the second with capacity from 11,000 Btu/h to 13,999 Btu/h.
- The Joint Petitioners also proposed splitting both product classes 5 and 8, but recommended splitting product class 5 at a different capacity than suggested by AHAM. This comment recommended a split at 28,000 Btu/h.

Product Class 5 Modifications

DOE based its considerations regarding the product class 5 split (room air conditioners without reverse cycle, with louvered sides, and capacity 20,000 Btu/h or more) on the following inputs:

- Individual discussions with manufacturers
- Research on available product sizes and available product efficiencies.
- Reverse engineering of three product class 5 units, including a 28,500 Btu/h unit and two 24,000 Btu/h units
- Engineering analysis of R-410A product class 5 baseline products at the 24,000 Btu/h and 28,000 Btu/h capacity levels.

DOE's research indicates that efficiency drops off monotonically as capacity increases.. For current product class 5, the current standard requires a minimum energy efficiency ratio (EER)[j] of 8.5 Btu/h-W. DOE's research found that no 2010 product of this class with a capacity higher than 28,000 Btu/h has an EER exceeding this minimum level, whereas products with lower capacity do exceed the minimum efficiency level. The trend for all room air conditioners with louvered sides without reverse cycle (current product classes 1, 2, 3, 4, and 5) is illustrated in Figure 5.6.48 below.

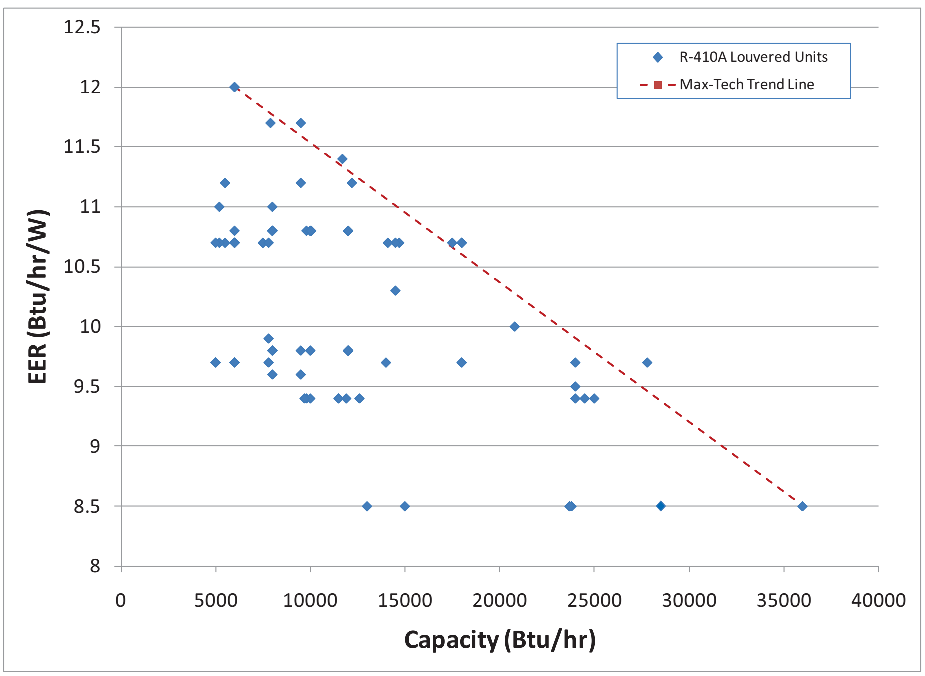


Figure 5.6.48 R-410A Louvered Products – Efficiency versus Capacity

DOE produced cost-efficiency curves for product class 5 products at both 24,000 Btu/h and 28,000 Btu/h capacity levels. Additional information of this analysis is available in chapter 5

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[j] Energy Efficiency Ratio (EER) is equal to the product's cooling capacity, expressed in Btu/h, divided by the power input, in Watts (W).

of this TSD. Table 5.6.51 shows the results of these analyses, which clearly show (1) much steeper increase in cost as the CEER increases and (2) significantly lower max tech for the larger capacity.

Table 5.6.51 Comparison of 24,000 Btu/h and 28,000 Btu/h Incremental Costs

Efficiency Level	PC5A – 24,000 Btu/h		PC5B – 28,000 Btu/h	
	CEER	Incremental Cost	CEER	Incremental Cost
1	8.47	$0.00	8.48	$0.00
2	9.0	$8.85	9.0	$23.52
3	9.4	$19.04	9.4	$50.27
4	9.8	$50.66	9.8	$229.01
5	10.15	$204.62	-	-

In addition, DOE's analysis of the 28,000 Btu/h size shows that two growths in product size are needed to reach these efficiency levels, including one to a very large size; for the 24,000 Btu/h, only one growth was required to achieve the same level of efficiency. Despite the additional product growth, the 28,000 Btu/h product did not reach the same max-tech efficiency level as the 24,000 Btu/h product. Additional information of this analysis is available in chapter 5 of this TSD. Table 5.6.52 shows the product sizes analyzed.

Table 5.6.52 Size Increases Examined During Room Air Conditioner Design Option Analysis – Product Classes 5A and 5B

Design Description	Width *(inches (in))*	Height *(in)*	Depth *(in)*	Volume *(cubic feet (cf))*	Weight *(lb)*
Product Class 5A					
Baseline	26	17.69	28.41	7.56	129.2
First Size Increase	27.75	17.94	30.94	8.91	136.4
Second Size Increase	-	-	-	-	-
Product Class 5B					
Baseline	26	17.69	28.41	7.56	129.2
First Size Increase	27.75	17.94	30.94	8.91	136.4
Second Size Increase	29.81	22.38	30.94	11.94	156.5

This analysis demonstrates the much greater potential for efficiency improvement in products lower than 28,000 Btu/h. DOE's decision to establish the new product classes 5A and 5B that take the place of the previous product class 5 is based on the stakeholder comments and DOE's analysis. DOE believes that the new product classes are needed to ensure establishment of meaningful efficiency levels over the full range of capacities.

Product Class 8 Modifications

DOE considered the following inputs when considering whether to split product class 8 (Non-louvered, non-reverse-cycle, capacity of 8,000 to 13,999 Btu/h):

- Individual discussions with manufacturers

- Research on available product sizes and available product efficiencies.
- Reverse engineering of six product class 8 units, including three 8,000 Btu/h units and three 12,000 Btu/h units
- Engineering analysis of R-410A product class 8 baseline products at the 8,000 Btu/h and 12,000 Btu/h capacity levels.

The max tech EERs of available room air conditioners without louvered sides using R-410A refrigerant are very dependent on capacity range. These products are designed to fit in sleeves installed in the building wall. Due to the heavy dependence of this market on replacement sales, as reported by manufacturers during interviews for the final rule analysis, there is little opportunity to adjust the physical size of the product. This is in distinct contrast to products with louvered sides, which are designed to fit in windows; this design allows more flexibility for size increase to improve efficiency. The max tech levels of non-louvered products are very dependent on the individual product's capacity. Products with capacity greater than 12,600 Btu/h are unable to meet the current ENERGY-STAR EER level. See Figure 5.6.49 for the results of DOE's survey of non-louvered, non-reverse-cycle R-410 products, completed in May 2010. DOE further notes that ENERGY STAR products in the capacity range 11,500 to 12,600 Btu/h require oversized sleeves. At a slightly higher capacity level, products cannot be designed to meet the DOE energy standard—the available data show that there are currently no available products having greater than 13,999 Btu/h capacity. During interviews, manufacturers reported that there is great technical difficulty in producing non-louvered products greater than 15,000 Btu/h that would meet the DOE's current efficiency standards.

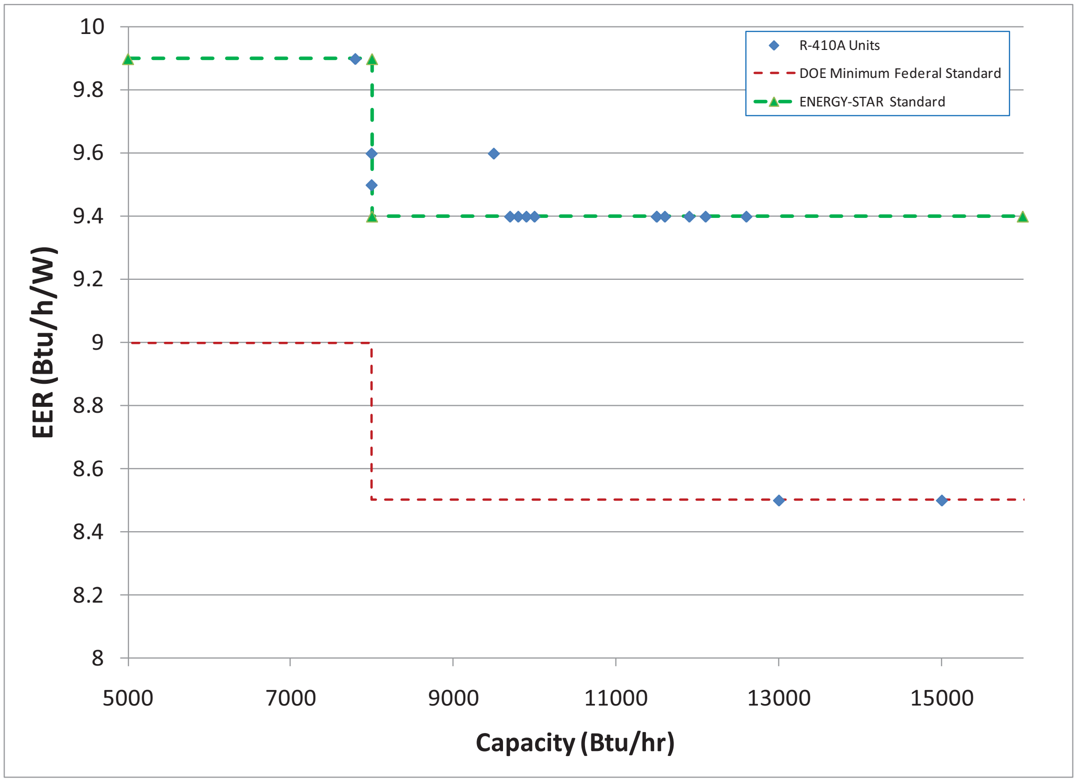

Figure 5.6.49 R-410A Products from DOE Survey of Non-louvered, Non-reverse-cycle Products

DOE produced cost-efficiency curves for non-louvered R-410A room air conditioners at 8,000 Btu/h and 12,000 Btu/h capacities, shown in Table 5.6.53 below. Additional information of this analysis is available in chapter 5 of this TSD. As with the product class 5 analyses, the results of the analysis of product class 8 show the significantly steeper increase in cost as efficiency level is raised above the baseline and the reduced max tech level for the higher-capacity product.

Table 5.6.53 Comparison of 8,000 Btu/h and 12,000 Btu/h Incremental Costs

Efficiency Level	PC8A – 8,000 Btu/h		PC8B – 12,000 Btu/h	
	CEER	Incremental Cost	CEER	Incremental Cost
1	8.41	$0.00	8.44	$0.00
2	9.3	$4.61	9.3	$11.72
3	9.6	$6.68	9.5	$15.39
4	10.0	$16.63	9.8	$26.06
5	10.4	$88.45	10.0	$93.36

This analysis demonstrates the much greater potential for efficiency improvement for the lower-capacity products. DOE's decision to establish the new product classes 8A and 8B that take the place of the current product class 8 is based on the stakeholder comments and DOE's analysis. DOE believes that the new product classes are needed to ensure establishment of meaningful efficiency levels over the full range of capacities.

5.6.2.11 Analysis Extension to All Product Classes

The process of extending incremental cost data for **room air conditioner** product classes not directly analyzed is discussed in this section. The methodology for estimating the incremental costs associated with efficiency increases for these product classes is described below.

During the preliminary analysis, DOE used interpolation and extrapolation methods, based on the IEER/CEER levels of the analyzed product classes, to estimate efficiency levels and incremental costs for the remaining product classes. DOE's downstream analysis were constructed just for the directly analyzed product classes. The other product classes have been assigned to each of the full analysis, based on determination of which of the fully-analyzed classes provided the best representation of life cycle costs. DOE used the criteria described in Table 5.6.54 below to establish the final product groupings.

Table 5.6.54 Product Class Grouping Criteria

Criterion	Description
Energy Use	Grouping of product classes with similar capacity and estimated operating hours. Table 5.6.55 provides a summary of representative capacities and operating hours by product class.
Ability to reach high efficiencies	Some product classes have limited potential for efficiency increase. Product classes without louvered sides, high-capacity products, and casement-slider or casement-only have limited potential for physical size increase, thus they also have reduced potential for efficiency improvement.
Extrapolated cost-efficiency curve	During the preliminary analysis, DOE estimated cost-efficiency curves for the non-analyzed product classes (see the preliminary TSD, chapter 5, section 5.6.2.7) DOE compared these extrapolated curves to the final rule results for the fully analyzed product classes to assist in selecting product class groups. DOE ranked each analyzed product class, in order of cost efficiency, to assist in this analysis.

Capacity and energy use characteristics for each product class are listed in Table 5.6.55 below. DOE used this information to assist in the grouping of product classes.

Table 5.6.55 Room Air Conditioner Representative Capacities and Operating Hours

Product Class	Description	Representative Capacity (*Btu/h*)	Estimated Operating Hours
With Louvers, Without Reverse Cycle			
1	< 6,000 Btu/h	5000	1281
2	6,000 to 7,999 Btu/h	6000	913
3	8,000 to 13,999 Btu/h	10,000	545
4	14,000 to 19,999 Btu/h	18,000	438
5A	20,000 to 27,999 Btu/h	24,000	331
5B	> 28,000 Btu/h	28,000	331
Without Louvers, Without Reverse Cycle			
6	< 6,000 Btu/h	5,000	1281
7	6,000 to 7,999 Btu/h	6,000	913
8A	8,000 to 10,999 Btu/h	8,000	545
8B	11,000 to 13,999 Btu/h	12,000	545
9	14,000 to 20,000 Btu/h	14,000	438
10	> 20,000 Btu/h	20,000	331
With Louvers, With Reverse Cycle			
11	< 20,000 Btu/h	12,000	545
13	> 20,000 Btu/h	14,000	331
Without Louvers, With Reverse Cycle			
12	< 14,000 Btu/h	10,000	545
14	> 14,000 Btu/h	14,000	438
Casement			
15	Casement-only	10,000	545
16	Casement-slider	10,000	545

The final product class groupings are presented in Table 5.6.56 below. These groupings were used in the subsequent LCC analysis.

Table 5.6.56 Room Air Conditioner Product Class Groupings

Group	Analyzed Product Class	Extrapolated Product Classes
1	1	-
2	3	2,4,11
3	5A	12
4	5B	10
5	8A	6,7,13,15,16
6	8B	9,14

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